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ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XVIII No. 10 OCTOBER, 1957

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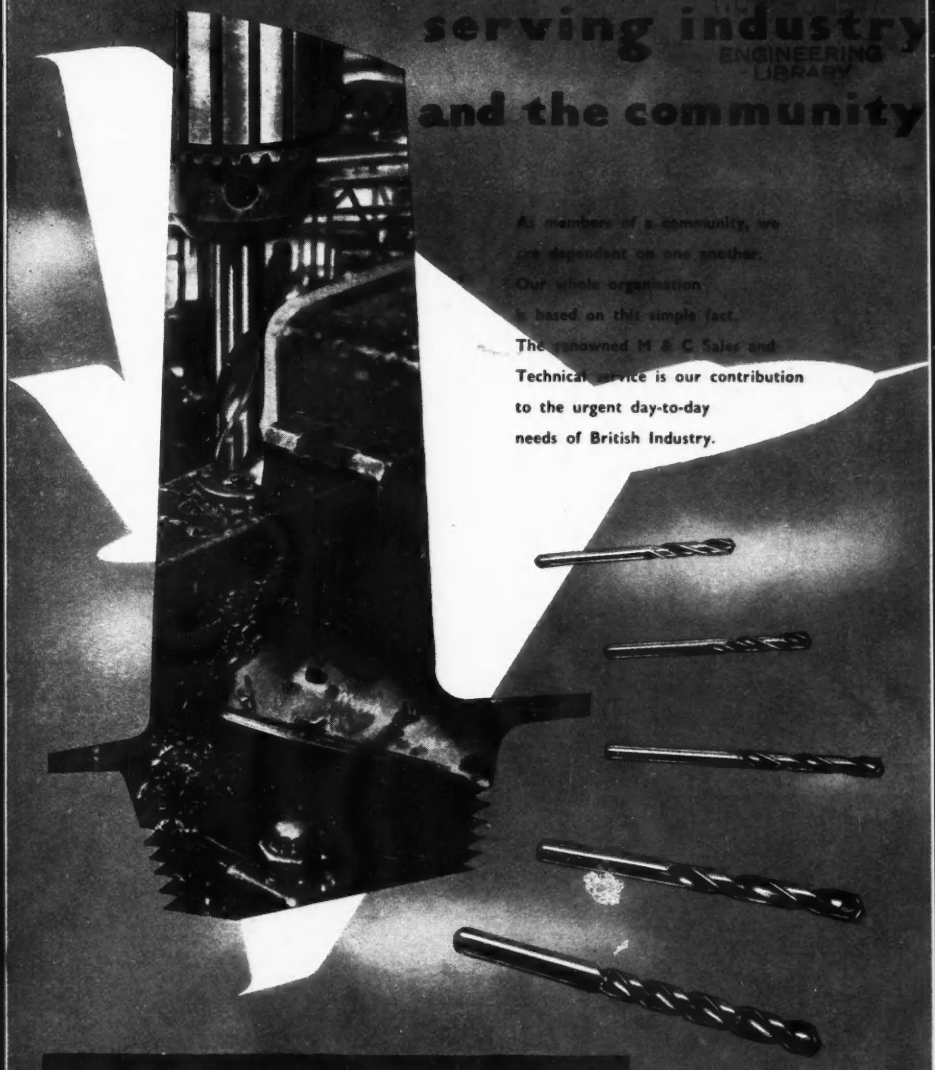

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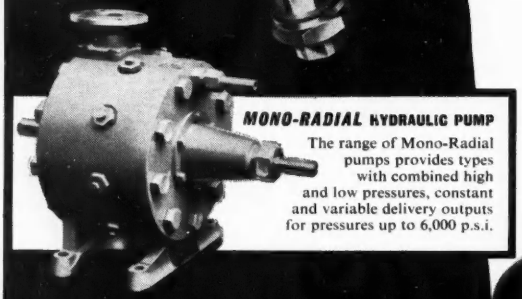

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CONTENTS

	Page
The Blue Pages	427
Design and Applications of "Solion" Electrochemical Transducers	431
The Use of "Ring-Springs" as Fastening Elements and in Other Applications	433
Designing Machine Tools for Automatic Control	436
Automatic Assembly Line for Needle Bearings	439
A High-Precision Lathe Headstock	442
Simplified Construction of Mixers and Stirrers on the "Convergence-Divergence" Principle	443
Water or Steam Injection in the Combustion Chambers of Gas Turbines	445
Non-Destructive Testing of Metals with Eddy Currents	451
5th European Machine Tool Exhibition	455
British Industrial Developments	465
Additional Abstracts	469
New Materials, Processes, and Equipment	471
News of the Month	475

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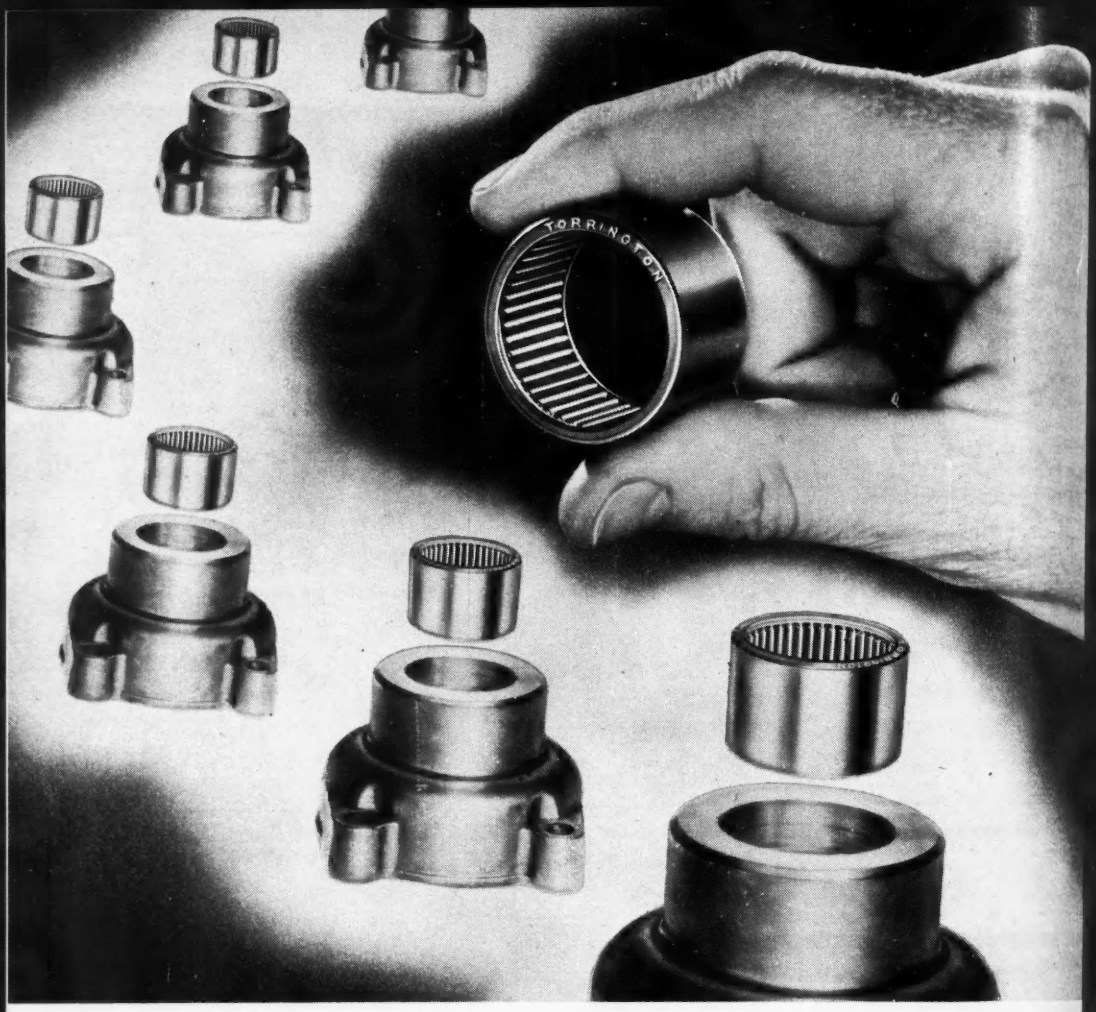

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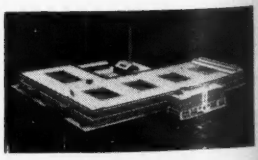

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *NEW TYPE OF DUST-SAMPLING DEVICE*

A new type of konimeter or dust-sampling device has been proposed which makes possible the separation from air or other gases of particles or aerosols over a range of sizes believed to affect the lungs of persons exposed to such atmospheres. Particles or aerosols suspended in air or other gases attain a terminal velocity under gravity which is dependent on the size, density, or mass of the particles and also on the viscosity and physical properties of the gas in which they are suspended. The particles can therefore be collected for examination by virtue of their tendency to fall out of the air. The particles or aerosols which are subject to respiratory action are of sizes lying within a range of the order of 0·5 to 5 microns. To secure representative sampling of this range of sizes it is sufficient to provide a device which secures the deposition of particles of sizes between the above limits. The sampling device developed makes it possible to effect the separation of the particles or aerosols in such a manner as to permit determination of the concentration of particles of differing sizes. For this purpose the air or gas to be investigated is made to travel along a determined path under a velocity such that the suspended particles or aerosols fall out of the air or gas stream according to their respective terminal velocities and are deposited at positions which differ according to the respective masses of the particles. In the device proposed, the air or gas stream is drawn into or forced through a channel of appropriate section, so that the particles are deposited on the lower surface of the channel, on which they are then distributed in accordance with their respective masses. The concentration of any particular size of particle or aerosol in the air may then be determined by reference to the volume of gas or air passing through the channel in a given time interval.

● *TOOL FOR FINISHING THE CYLINDER SURFACES OF INTERNAL COMBUSTION ENGINES*

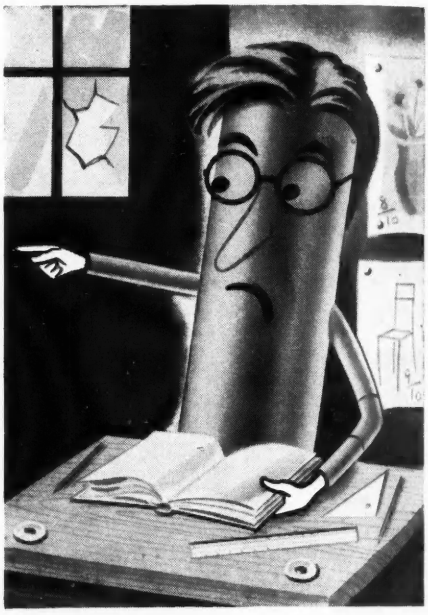
Boring out an engine cylinder usually results in the bore having a slight ovality and a slight taper in the axial direction, whilst the surface produced by the boring tool is grooved circumferentially, generally to a depth not less than 60 microinches, and requires to be finished to a smoother condition. It is not, however, desirable to reduce the bore surface to an extremely smooth condition, as this would to a large extent diminish its property of retaining an adequate oil film. This finishing of bored cylinder surfaces is usually performed with a rotary honing tool, but, as a recent patent specification points out, it is found in practice that this method, which involves the removal of metal from the crests between the grooves, not only results in particles of the abrasive hone material becoming embedded in the bore surface, thus contributing to cylinder wear, but also tends to increase any bore distortion produced during the boring operation. The patent referred to has for its object the provision of a new tool which will produce the requisite finish of the cylinder bore surface without abrasive action and without distorting the bore or increasing any distortion already present. The new tool exerts a pressure-rolling action on the surface, so as to remove the crests between the grooves and thus reduce their depth. The tool comprises an annular series of floating rollers, which are mounted for free rotation and a movement radially free with respect to the end rings of a rigid cage. Spring loading is applied to the rollers by opposed conical rolls which are positively rotated and pressed axially towards each other by springs. The conical rolls co-operate with the complementary conical ends of the rollers, so that the spring action via the conical rolls causes the rollers to be forced radially outwards and brings them into rolling contact with the cylinder bore surface. The floating rollers should preferably have a slightly inclined disposition, so that they impart to the tool an automatic axial feed.

● *METALLO-ORGANIC POLYMERS AS NUCLEAR FUEL MATERIAL*

It is reported that polymers of mono- and di-carboxylic acids, with uranium chemically bound in, may prove suitable as nuclear-reactor moderator-fuel materials. Promising properties are high values of the number of hydrogen atoms per cubic centimetre, excellent heat and radiation stability, and complete homogeneity, even at maximum metal content. Polymers containing lead or lithium in place of uranium may be useful shielding materials. A technique is now being studied for synthesizing organo-metallic polymers in which the starting material is a preformed polymer. The initial polymer is chosen for its radiation stability, and a second material,

"I WAS A SNEAK"

—Master H. W. Pipe owns up



I was always in hot water — or rather hot water was always in me — when I left the boiler-room. But then I wandered about the school, improperly dressed. I used to dissipate my heat in draughty corridors. By the time I reached the dorm' radiators, I was as tepid as school tea!

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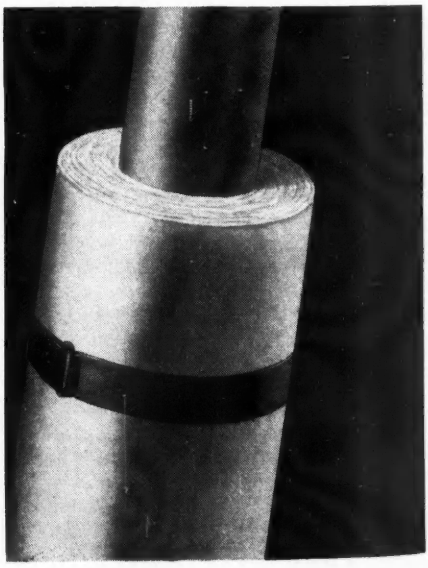

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also radiation-resistant and capable of adding acid groups, is grafted to this polymer by means of gamma irradiation. This graft copolymer is then treated with acid and subsequently with a metal hydroxide to produce the metal polymer. The technique allows preparation of organic polymers with a wide variety of metals, which are chemically bound into the polymer, making the system homogeneous. Polymers of uranium, lead, lithium, iron, and combinations thereof have been prepared, and some of their physical characteristics have been evaluated. The composition of these polymers can be adjusted so that the weight ratio of metal to hydrogen and metal to carbon can be significantly varied. The weight composition of metal can be as high as 60% for the heavier metals. The addition of metals such as cadmium, thorium, and others is also possible. Heat-transfer studies, as well as detailed studies of fission-product formation and elimination, are required if the uranium polymer is to be considered for use as a homogeneous moderator-fuel element. Further investigations are reported to be in progress to evaluate the shielding ability.

● *PRECISION BOROSILICATE-GLASS CORING FOR LIGHT ALLOYS*

There are certain problems inherent in the use of sand cores which limit their use in the production of passageways of small diameter in castings of light alloys such as aluminium or magnesium. When molten metal is introduced into the casting cavity so as to contact with sand cores, gases are formed by volatilization of the chemical inhibitors and core binders. These gases cannot be allowed to bubble through the molten metal, but must be permitted to escape through the core interior and out to atmosphere. Sand cores have a natural permeability, but in long, thin, or intricate cores it is necessary to form an interior cavity or vent for the escape of these gases. The interior cavity in the core naturally decreases its strength and thus increases the chances of core breakage. In thin, intricate cores having unsupported lengths of more than a few inches, it is common practice to insert a steel wire for support. However, these steel wires introduce inaccuracies into the core during casting, owing to the difference in thermal expansion between the sand and the steel wires. The thermal expansion is apt to cause warpage of the core, especially in intricate shapes. It is claimed that these difficulties have been successfully solved by a recent proposal, which consists of placing in a mould a borosilicate glass core corresponding to the size, shape, and location of the desired passageway. The molten metal is then poured into the mould and allowed to solidify, and the casting is then removed from the mould. The glass core is removed from the casting by selective corrosion with a chemical reagent, leaving clean and smooth-surfaced passageways in the casting. Borosilicate glass is commercially available in a variety of shapes and sizes and is relatively inexpensive, and the accurate retention of the core dimensions with the use of this glass is the result of its high resistance to thermal shock and poor heat-transfer characteristics.

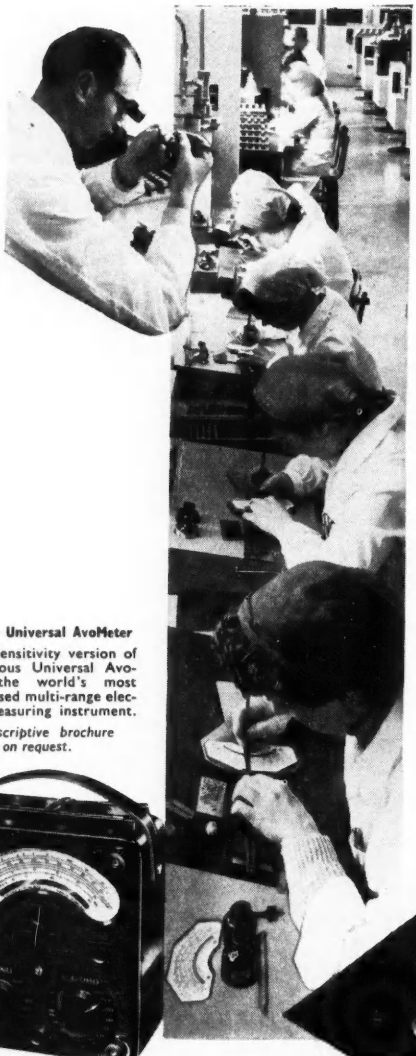
● *IMPROVED IMPACT EXTRUSION OF SEAMLESS TUBULAR PIECES*

A recent patent describes an improved extrusion method of manufacture of tubular pieces, especially those of aluminium, as used for the manufacture of preserve containers. In the extrusion press, which produces the seamless tubes from hollow billets, the billets are extruded in the direction of movement of the press ram, the press operating continuously. Severing of the press discard is effected automatically at the end of each press stroke by a punch which moves axially in the press ram and which springs forward under the influence of a spring to project a cutting edge beyond the working face of the press ram, overcoming the shear resistance of the discard. This extrusion press is claimed to have a comparatively high output and to make extrusion possible with any desired thickness and length of wall. The press is coupled through a control shaft with a revolving disc, on which a number of receiving mandrels are arranged, these mandrels being brought successively into axial alignment with the extrusion aperture of the press in timed relation with the plunger stroke. At succeeding stations the mandrels are rotated about their own axes, and separating knives then cut the tube on the mandrel into pieces of the desired length. At the last station the pieces are removed from the mandrel by means of an automatic stripper. The container can then be completed in the usual manner by seaming a bottom onto the tube or jacket. The mandrels may be made as split mandrels so as to secure the tube against rotation over its entire length, and the subdivision of the tube into, say, five lengths can then be simultaneously effected. It is stated that in a plant of this type 60 tubes can be extruded per minute and divided into 300 lengths during the same time.

● *DIE-CAST OFFSET-TOOTH SPUR-GEARS*

The die-casting of helical gears involves the use of a highly complex ejection mechanism which must rotate in a very precise manner as the gear is ejected from the die. It has also been found that the helical angle must be low, because the torque required to eject a gear with a helical angle is so great that shearing of the teeth almost invariably results. To secure the advantages of a helical gear with any desired helix angle and

A Good Sign ...



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at the same time to ensure that the part can be die-cast, a new gear design has been developed, in which the gear consists of two offset rows of teeth with a web between the rows. As cast, the web is flush with the tooth faces; to finish, the web is machined out to below the pitch diameter, so that maximum shear strength is preserved. This gear is readily castable, and ejection is as simple as for any other straight gear. Moreover, the tooth contour can be as close to a true involute as the die-maker can produce. It is claimed that the construction of this gear is such that small gears have the equivalent strength of much larger, straight-toothed spur-gears, with a resulting saving in materials. A further saving is made in die-construction costs, since a straight hobbing tool can be used to form the cavities. Any castable metal can be used for the manufacture of this gear, and, in fact, other precision manufacturing methods, such as shell-moulding, investment casting, powder metallurgy, and permanent-mould casting, can also be used. It is claimed that the design of this gear gives it a smoother running action, quieter operation, and higher efficiency than can be obtained with ordinary spur-gears.

● *HEAT-RESISTANT MAGNESIUM-THORIUM ALLOYS*

New magnesium-thorium alloys are being developed which combine low weight with high-temperature strength and are therefore particularly suitable for aircraft engines, missiles, and air-borne equipment in general. The specific gravity of thorium is 11·7, as compared with 1·74 for magnesium, but the rapid increase in density with increasing thorium content of the alloy is not of practical significance, because commercial magnesium-thorium alloys contain only 1 to 3% by weight of thorium. Thus, the densities of such alloys are not greater than most of the older magnesium alloys containing aluminium and zinc as the principal alloying constituents. The outstanding characteristic of the new alloys is their resistance to creep at elevated temperatures. Generally speaking, the creep resistance values of magnesium-thorium alloys at 500 to 600°F are reported to be the highest observed in any magnesium alloy to date. In extrusions, the first few percent of thorium increases the creep limit much more rapidly than it does in castings. At higher thorium contents the extruded alloys are found to have a lower creep resistance than the cast alloys. However, the values are still considered exceptional for extruded magnesium alloys. Manganese added to magnesium-thorium alloys has been found markedly to enhance temperature resistance and to result in exceptional static strength in the range of 500 to 900°F, and in high creep resistance at 500 to 700°F. No cast magnesium-thorium-manganese alloy has, however, yet progressed beyond the development stage. It is reported that wrought magnesium-thorium alloys can be formed by the usual techniques, except that somewhat higher temperatures are required. In addition, they have outstanding welding characteristics and require no subsequent stress relief. They show no evidence of stress-corrosion failure and may be protected against general chemical corrosion by most of the available chemical surface treatments.

● *GLASS COATINGS FOR METAL*

It is predicted that glass coatings will soon be used to protect metal parts such as bearings, gears, cams, and pistons. If glass is properly bonded to steel, it cannot be separated from the metal until the yield point of the base metal is exceeded, the adhesive strength of the glass to metal ranging up to 10,000 psi. Among the favourable properties of glass which make it a promising coating material are its resistance to weathering and corrosion, its non-porosity, its high dielectric strength, its resistance to high temperatures, and the fact that its coefficient of thermal expansion can be varied to meet requirements in a given case. When using the glass coating process as now developed, the controlling factor is the strength of the part to be coated at the temperature that has to be maintained in order to produce the glass coating. Proper metal fabrication with a view to eliminating the danger of distortion, such as sagging, bulging, etc. at the firing temperature of the glass coating, is therefore essential. Welds must be free from pinholes, dirt, and grease, and this is ensured by baking electrodes to at least 600°F to remove all moisture and to prevent the formation of hydrogen. Glass can be fused to copper, aluminium, silver, and gold, but its major application is to low-carbon steels. Prior to application of the coating the base metal must be chemically or mechanically cleaned. A special clay, water, and frit are milled to form a slip which is a suspension of finely ground glass particles, this slip being applied by spraying, dipping, or flow coating, after which the piece is then dried and baked in an oven. The temperature required depends upon the composition of the glass, but is usually 1600°F.

● *CENTRIFUGAL METHOD OF MANUFACTURING GLASS FIBRE*

A new glass-fibre manufacturing device has been proposed in which the glass in a plastic state is projected at high temperature from a centrifuge body through a number of superposed rows of projection orifices. After projection, the glass is subjected to the action of a gas at high speed and high temperature which escapes from the orifices of an annular combus-

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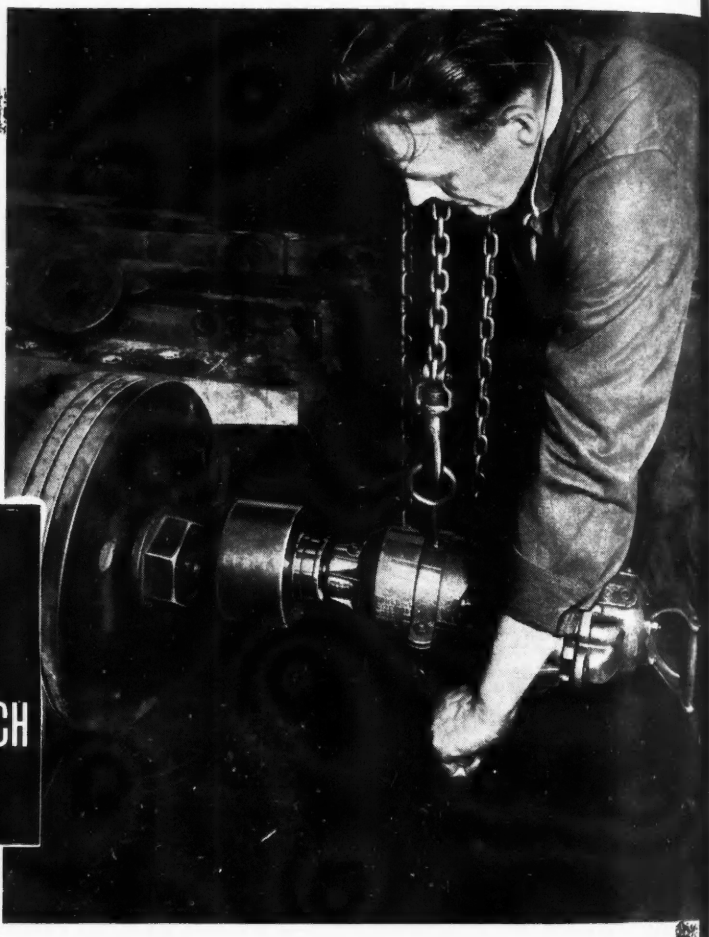

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tion chamber. In this way the glass threads leaving the centrifuge orifices are subjected to a sudden change in direction and to an energetic stretching action which converts them into very fine fibres. By distributing the projection orifices in several rows on the peripheral wall of the centrifuge a simultaneous stretching of the glass projected out of the orifices is obtained, even if the orifices are aligned in the direction of the current of hot gas. It is stated that it has actually been possible to observe clearly the different individual tracks formed by the projected melted material from each of the rows of the orifices. However, the fibres thus formed can be entrained below the centrifuge and also tend to regroup themselves in a still plastic state. This happens particularly if the centrifuge is surrounded by a combustion chamber with closely spaced slots or holes for the expansion of the hot gas, forming below the centrifuge a vortex which creates a zone of depression, and causing the fibres to agglomerate. This phenomenon can result in a number of serious inconveniences, especially the sticking of the fibres under the centrifuge and the sticking together of the regrouped fibres. This can, however, be overcome by providing a space for the entry of air to the interior of the ring formed by the hot gas escaping from the gas orifices. A centrifuge of this type is operated at 3000 rpm, and the glass is projected from the orifices at 1300°C.

●*PULL-REAMING FOR BORES IN LONG CYLINDRICAL TUBES*

Push-reaming is the conventional method of producing straight bores in long cylindrical tubes, but a recent report claims that pull-reaming has several theoretical advantages. When a boring bar is put under tension in pull-reaming, the straight-line forces set up resist deflection, and this resistance will increase with increasing depth of cut and number of cutters. In push-reaming, on the other hand, forces causing deflection increase with larger cutter loads. These considerations have led to a decision to try out pull-reaming of 90-mm gun barrels. As a first step, the application of pull-reaming was limited to semi-finishing work, as control of bore size was not maintained consistently enough to warrant the use of pull-reaming for finishing cuts. It is anticipated, however, that a finish pull-reamer will be perfected in the near future. The problem of chip extraction in pull-reaming was found to be similar to that in trepanning, and close control of chip formation is essential. In addition, development work is required to improve this control. Chatter and chip-flow problems will be minimized when pull-reaming is applied to tubes with larger bores, as the ratio of bar diameter to length will be more favourable, improving rigidity. By using a hollow-bodied reamer in larger bores, the possibility of chips accumulating within the reamer will be reduced, since the inside diameters of the reamers will be proportionately larger. In pull-reaming, high cutting loads improve accuracy. With large cutter bodies, it will be possible to use more cutters, and these can be adjusted for a maximum depth of cut, the only limitation to depth of cut being the amount of pressure the cutter body can withstand.

●*ELECTRONIC MEASUREMENT OF COATING ADHESION*

The ever-increasing speeds of modern aircraft have shown the need for test methods to evaluate the adhesion properties of the protective coatings used in such aircraft. A recent research report gives the results of a study made of available adhesion-measuring instruments, and it is reported that the adherometer is one of the most promising instruments investigated. In this apparatus, which measures the force required to strip a coating from a metal surface, a coating sample, mounted on a motor-driven plate, travels under a weighted knife, and the variable stripping force encountered as the coating is removed is reflected on a dial gauge. However, this variable force is difficult to follow by dial-gauge readings, the process of recording and averaging many readings during a stripping run is lengthy and laborious, and the results obtained are not always reliable. To increase the speed, ease, and precision with which adherometer measurements can be made, an electronic averaging device known as the " Integrometer " has been developed, in which the variable stripping force measured by the adherometer is converted into electrical impulses. These impulses are then added to give a simple average value which can be read directly from a standard recorder. The Integrometer contains a Wheatstone-bridge circuit which includes strain-gauges, an amplifier, an integrating circuit, and a meter circuit. The output from the beam and strain-gauge assembly of the cutting head is fed to the amplifier, and the integrating circuit converts the amplified electrical impulses to an output voltage proportional to the average value of the variable stripping force. The integrated voltage is then applied through the meter circuit to a standard recorder, which draws a straight line, whose length, after a precisely timed interval, is proportional to the average value of the varying voltage impressed on the integrating circuit during the stripping operation.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

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Design and Applications of "Solion" Electrochemical Transducers

(From *Machine Design, U.S.A.*, Vol. 29, No. 17, August 22, 1957, pp. 102–105, 6 illustrations.)

In the Blue Pages of our issue for September 1957, some details were given of "solion" electrochemical electronic devices. This article gives additional information on these new transducers and some of their applications.

DEVELOPED at the U.S. Naval Ordnance Laboratory and designated "solions" because their control and sensing characteristics involve the motion of ions in solution, these new electrochemical transducers are highly sensitive to changes in temperature, pressure, light, sound, or motion. Solions are of small size and have a low power consumption, and can accomplish many of the functions which up to now have been performed only by electronic tubes and transistors. After full development, they may be more selective, sensitive, and efficient in many applications than electronic tubes or transistors, and it is fully expected that they will eventually make possible smaller, simpler, and more economical instrumentation.

Even now, many transistorized circuits are more complicated than electrochemical circuits performing the same function, while considerably less electrical power is required by a solion circuit than in a comparable transistor circuit. In terms of size and cost, it is claimed that a vacuum-tube circuit would be larger, heavier, and more expensive than an electrochemical circuit designed for the same function.

The main disadvantage of solions is the limited operable frequency range, at present lying between 0 and 200 cps. Also, the solion cell itself is bigger than transistors and is larger in some dimensions than many miniature vacuum tubes.

Generation of electrical current occurs in the device when ions are caused to move between electrodes through an iodine solution. Current flow is excited initially by a low-voltage, dry-cell battery, connected in series with the electrochemical unit, as shown in Fig. 1. Solion current is then sustained and varied by outside stimulation of the unit with changes in temperature, pressure, light, sound, and motion.

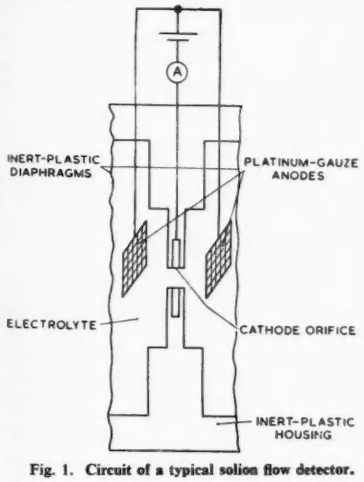

Fig. 1. Circuit of a typical solion flow detector.

The solion is polarized by a specially designed battery, developed at the Naval Ordnance Laboratory. Other types of low-voltage batteries may, however, be used. The NOL battery is a silver-lead, alkaline, rechargeable dry battery with a long shelf life and possesses the ability to deliver 0·9 V over long periods. Highly shock-resistant, it is estimated to have a useful life of ten years or more.

FLUID-FLOW DETECTORS

By careful control of electrode design, it is possible to obtain linear or logarithmic current outputs as a function of fluid flow.

A typical flow detector, with polarizing battery and ammeter, is shown in Fig. 1. The electrodes may be of any metal which is inert to the electrolytic system used, but, in this particular example, platinum electrodes are used in an electrolytic system of iodine and potassium iodide in water. Cathodic reduction of iodine is made the controlling reaction by using a low concentration of iodine and a high concentration of the supporting electrolyte, i.e., potassium iodide. Current in the system is evidently controlled by the number of negative iodine ions which come into contact with the cathode. When there is no electrolyte flow through the cathode orifice, the current is controlled by diffusion; fluid flow of the electrolyte increases the number of available negative iodine ions at the cathode, and the current in the system increases. The reactions within the detector are reversible and there is no depletion of the unit during the chemical processes.

Other electrolyte systems may be used, e.g., ferricyanide-ferrocyanide, bromine-bromide, ceric-cerous, ferric-ferrous, etc. It is only necessary that they be reversible redox systems, i.e., reversible, chemical reduction-oxidation systems.

Fig. 2 shows the type of response which may be obtained from a detector system with an electrode geometry which yields a logarithmic current output with respect to acceleration of the electrolyte. A range of three decades in acceleration was achieved by a simple instrument consisting of an electrochemical detector, a battery, and a micro-ammeter. No switches or other controls were used to cover the three log steps of acceleration from

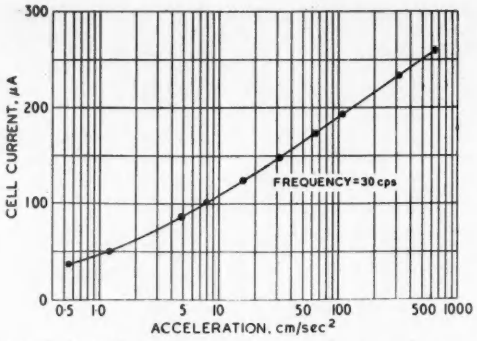

Fig. 2. Typical calibration curve of a solion detector used as an accelerometer.

1 to 10,000 cm/sec.^{2} Motion is applied along the axis of cylindrical symmetry of the accelerometer cell.

The cell in Fig. 1 was primarily designed for the detecting and metering of acoustic energy or a.c. pressures, power consumption being from 1% to 0·1% that required to operate a transistor. A more satisfactory design of cell for d.c. flows and pressures is shown in Fig. 3. In this design, an additional cathode is placed in the right-hand compartment, so that the bias voltage transfers the iodine from this side to the anode side, resulting in a final concentration of virtually zero in the cathode side.

The working or detecting cathode consists of a small piece of closely woven platinum gauze situated in an orifice between the two compartments. Flow from left to right (from concentrated to dilute solution) produces an electrical signal directly proportional to the magnitude of the flow. By suitable design of the detecting cathode, linear current outputs are obtainable over a range of four orders of magnitude in the flow rates. Units of this type have been constructed with a sensitivity of 1 dyne/cm^2.

The unit in Fig. 3 is also a rectifier, in that fluid flow from right to left will not produce a current, since no iodine is carried over the detector gauze. A full-wave detector may easily be constructed by using two anode compartments and two detector gauzes.

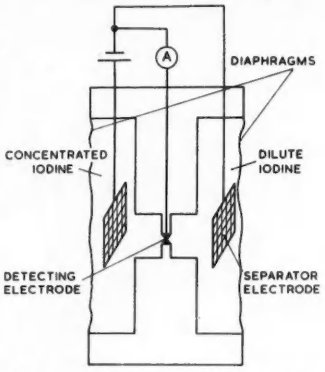

Fig. 3. Separated solion detector designed primarily for measuring d.c. flows and pressures.

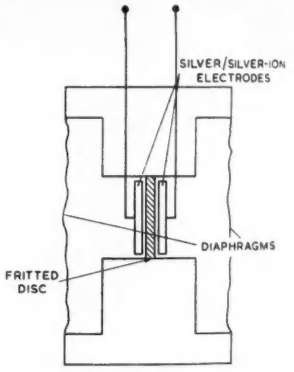

Fig. 4. Electro-osmotic cell for converting electrical energy into fluid flow.

Electro-Osmotic Cells

To perform various mathematical operations on the output currents of the flow detectors previously described, it is necessary to have a unit which carries out the reverse operation of converting low-power electrical signals into fluid flows. Thus, electrical and fluid-flow signals may be fed from unit to unit in the same way as currents and voltages are fed through electronic networks. In addition to simple amplification, several mathematical operations may be carried out on the original incident signal or signals in this way, e.g., products, ratios, derivatives, etc.

The simplest and most reliable method of carrying out this reverse effect is by the use of electro-osmosis, a process involving the movement of liquid with respect to a fixed solid (e.g., a porous diaphragm or a capillary tube) as a result of an applied electric field. An electro-osmotic cell (Fig. 4), consists of a fritted-glass disc dividing a cell into two compartments, with electrodes on each face of the disc. Operating characteristics can be made to vary over extremely wide ranges by control of disc porosity, thickness, diameter, choice of working liquid, etc. The important point, however, is that the fluid flow produced by an applied voltage is linear with the value of voltage.

Fluid flow for a 30-mm diameter, 20-mm thick disc of this type is in the neighbourhood of 10^{-3} cc/sec at 1 volt applied to the electrodes. A flow rate of 10^{-5} cc/sec through a separated detector of the type shown in Fig.3 will yield some 100 microamperes output, so that the values of flow rate produced by the electro-osmotic cell easily cover the working range of the other electrochemical units.

Power gains of the order of 330 may be obtained by combining these electrochemical units with the electro-osmotic cell with a linearly operating separated detector.

Present and Future Applications of Solions

Although solions were originally developed for ordnance use, their commercial applications in industry are considered quite feasible, and it is believed that, even in their present state of development, they can advantageously be applied to various types of circuitry, including integration units requiring continuous high-precision recording in acceleration (inertia) guidance systems in aircraft ; so-called " rate " circuits or derivative systems for providing maximum speed and accuracy in the operation of heat controls, burglar and fire alarms, furnace regulators, and pressure indicators ; and sound-sensitive meters. They are also suitable in product circuits involving electrical derivatives and/or hydraulic flow, and in electrical and small-signal hydraulic amplifiers.

Flight Integrators:—

Test models of an electrochemical flight integrator have already been produced industrially and demonstrate the simplicity and accuracy of these components. The navigational instrument, about 2 in. in diameter by 2 in. in length, operates on the inertia principle. Once started in motion in one direction, it retains a " memory " of its original course and instantly senses directional

(*Concluded on page 454*)

The Use of "Ring-Springs" as Fastening Elements and in Other Applications

By E. KREISSIG and O. SCHMIDT. (From *Industrie-Anzeiger*, Vol. 79, No. 50, June 21, 1957, pp. 26–29, and No. 58, July 19, 1957, pp. 25–29, 24 illustrations.)

A GIVEN volume of metal can absorb more energy in tension or compression than in bending, torsion, or shear because, in tension and compression, all the "fibres" of the material are stressed equally. The "ring-spring" utilizes this fact in order to operate with the minimum volume of material. In addition, the fact that, when a spring is loaded repeatedly, the fatigue strength of the material in compression is higher than it is in tension is also of importance.

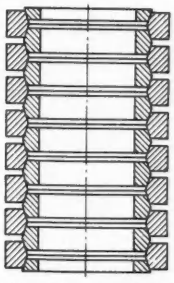

Fig. 1. Column of ring-spring elements.

The ring-spring consists essentially of inner and outer rings, with conical rubbing surfaces between them, as can be seen in Fig. 1, which shows a column of these ring-spring elements. If μ is the coefficient of friction between the conical rubbing surfaces of the inner and outer rings

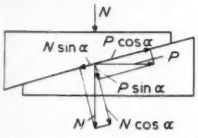

Fig. 2. Internal forces between the inner and outer rings.

of the spring, α the angle between the axis of the spring and the generator of the cones, P the axial loading, and N the resultant radial force acting between rings in contact, it can be seen from Fig. 2 that

$$P\cos\alpha = N\sin\alpha + \mu\,(N\cos\alpha + P\sin\alpha) \quad .. \quad (1)$$

or

$$N = P\,\frac{1-\mu\tan\alpha}{\tan\alpha+\mu} \quad .. \quad .. \quad (2)$$

Similarly, when the spring is unloaded, the axial release force P_r is determined by

$$N\sin\alpha = P_r\cos\alpha + \mu\,(N\cos\alpha + P_r\sin\alpha) \quad .. \quad (3)$$

or

$$N = P_r\,\frac{1+\mu\tan\alpha}{\tan\alpha-\mu} \quad .. \quad .. \quad (4)$$

For a frictionless spring (i.e., $\mu = 0$), the axial load is

$$P_0 = N\tan\alpha \quad .. \quad .. \quad .. \quad (5)$$

The total work A done by the force P in compressing the ring-spring a distance a is

$$A = Pa/2 \quad .. \quad .. \quad .. \quad (6)$$

If A_e is the elastic energy stored in the compressed spring, $A/A_e = P/P_0$, so that

$$A = A_e\,\frac{\tan\alpha+\mu}{\tan\alpha\,(1-\mu\tan\alpha)} \quad .. \quad .. \quad (7)$$

Except in the case of rings of appreciable radial thickness, the value of $\mu\tan\alpha$ is small and can be ignored, so that simplified equations for general calculations are

$$P = N\,(\tan\alpha + \mu) \quad .. \quad .. \quad .. \quad (8)$$

$$A = A_e\,\frac{\tan\alpha+\mu}{\tan\alpha} \quad .. \quad .. \quad .. \quad (9)$$

$$A_r = A\,\frac{\tan\alpha-\mu}{\tan\alpha+\mu} \quad .. \quad .. \quad .. \quad (10)$$

where A_r is the work done during release of the spring.

NUMERICAL EXAMPLE OF SPRING CALCULATIONS

Suppose that a buffer spring of length $l = 19{\cdot}25$ in. and outside diameter $D_o = 6{\cdot}5$ in. is required to carry a maximum axial load $P = 30$ tons with a total compression $a = 3{\cdot}25$ in. The spring is assumed to be fully compressed, so that the radial end faces of the rings are in contact. All rings are assumed to be equally stressed, the basic allowable stress f being 64 tsi; the modulus of elasticity $E = 13{,}400$ tsi, the coefficient of friction $\mu = 0{\cdot}16$, and $\tan\alpha = 0{\cdot}25$.

(*a*) *Basic Design* :—

From eq. (6), the work done in compression $A = 48{\cdot}7$ tons-in. From eq. (9), the elastic energy absorbed $A_e = 29{\cdot}8$ tons-in. The volume V of metal required $= 2A_eE/f^2 = 195$ cu in.

For a solid ring-spring,

$$V = \frac{\pi}{4}(D_o^2 - D_i^2)(l-a)$$

so that the inside diameter D_i can be calculated as

$$D_i = \sqrt{D_o^2 - \frac{4V}{\pi(l-a)}} \quad .. \quad .. \quad (11)$$

from which, in this case, $D_i = 5{\cdot}15$ in. Hence, the mean diameter $D_m = (D_i + D_o)/2 = 5{\cdot}82$ in.

Now, suppose that, when the ring is fully compressed, the diameter D_i' of the centre of gravity of the inner ring is $D_i' = D_m - 2x$, and the diameter D_o' of the outer ring is $D_o' = D_m + 2x$ (Fig. 3). The changes in these diameters on release of the spring add up to

$$\lambda = \lambda_i + \lambda_o = (D_m - 2x)(f/E) + (D_m + 2x)(f/E) = 2D_mf/E \quad .. \quad .. \quad .. \quad (12)$$

A corresponding radial loading of each ring would create a radial gap $\lambda/2$ between each inner and outer ring.

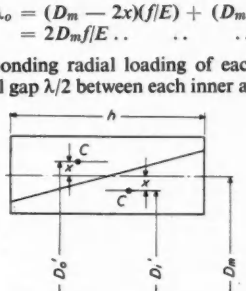

Fig. 3. Centres of gravity and their diameters in a fully compressed ring-spring.

Fig. 4. Ring-spring used as a fastening element.

The axial gap would be $\lambda/(2\tan\alpha)$, and a spring with n conical contact surfaces would shorten axially by n times this axial gap, so that its actual compression a would be

$$a = n\lambda/(2\tan\alpha) = n D_m f/(E\tan\alpha) \quad .. \quad (13)$$

From eq. (13) the number of contact surfaces n is in this case $n = 29{\cdot}2 \approx 30$.

Hence, the spring can have 14 inner and 15 outer rings with double conical surfaces, plus two terminal inner rings with single conical surfaces.

The axial depth h of each ring is given by

$$h = (l - a)/n \quad .. \quad .. \quad .. \quad (14)$$

from which, in this case, $h = 0{\cdot}53$ in.

(*b*) *Maximum Stress* :—

The expansion of the outer rings gives rise to an additional bending stress f_b in the extreme fibre at a distance y from the neutral axis, when this axis suffers a change in curvature from its initial radius R_1 to its final radius R_2 under load, so that

$$f_b = y\left(\frac{E}{R_2} - \frac{E}{R_1}\right) = yE\frac{R_1 - R_2}{R_1 R_2}$$

The neutral axis coincides with the locus of the centres of gravity, in this case a circle of radius $D_o'/2$, so that $R_1 - R_2 = (D_o'/2)(f/E)$ and $R_1 R_2 \approx (D_o')^2/4$

$$\text{Hence, } f_b = 2fy/D_o' \quad .. \quad .. \quad .. \quad (15)$$

Now, as already stated, $D_o' = D_m + 2x$; assuming a value of $x = 0{\cdot}12$ in., $D_o' = 6{\cdot}06$ in. Also, as $y = (D_o - D_o')/2$, in this case $y = 0{\cdot}22$. Hence, from eq. (15), $f_b = 4{\cdot}7$ tsi.

Moreover, the compressive force N acting on the conical contact surface of area F produces a compressive stress $f_c = N/F$, which is accompanied by a transverse tensile stress $f_t = 0{\cdot}3 f_c$, where 0·3 is Poisson's ratio.

In the present example, from eq. (8), $N = 73{\cdot}2$ tons. Also, $F = \pi D_m h = 9{\cdot}7$ sq in. Consequently, $f_t = 0{\cdot}3N/F = 2{\cdot}3$ tsi.

Thus, the maximum tensile stress $f_{max} = f + f_b + f_t = 64 + 4{\cdot}7 + 2{\cdot}3 = 71$ tsi, so that the spring steel must have a yield strength which is higher than this figure.

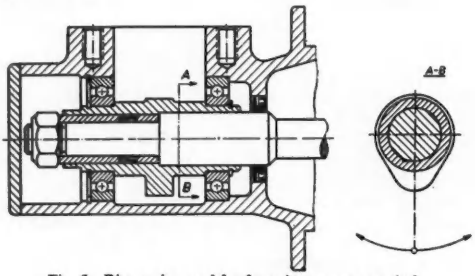

Fig. 5. Ring-spring used for fastening a cam to a shaft.

(*c*) *Improved Design* :—

Since the fatigue strength of the spring steel is higher in compression than in tension, the inner compressed ring may well be stressed more highly. If the ratio of compressive to tensile strength is taken as $k = 1{\cdot}25$ for the buffer spring, and a basic tensile stress $f = 64$ tsi has been allowed for the outer ring, the inner ring may be subjected to a stress $f' = kf = 80$ tsi. In the basic design, the common radial thickness of the inner and outer ring was $t_o = t_i = (D_o - D_m)/2 = 0{\cdot}34$ in.

For an equal height h, the inner ring, if stressed more highly, may have a mean radial thickness $t_i' = t_o/k = 0{\cdot}27$ in. The elastic energy A_e' which the spring can now absorb is $A_e' = A_e(k + 1)/2 = 33{\cdot}5$ tons-in.

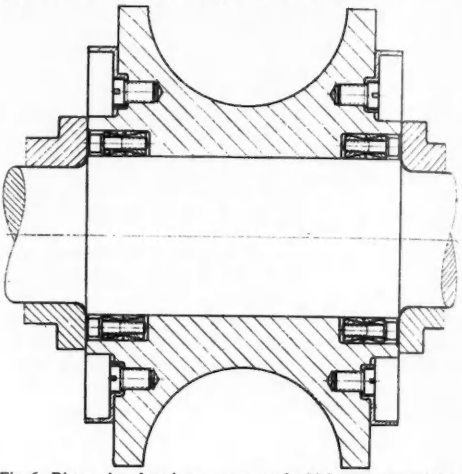

Fig. 6. Ring-spring clamping arrangement for high torque transmission.

For an equal axial loading of 30 tons, the compression a' of the new spring will be $a(k + 1)/2 = 3{\cdot}65$ in. If, however, it is desired to retain the original deflection $a = 3{\cdot}25$ in., the values of n, h, and D_i must be changed accordingly, as follows :—

$$n' = 2n/(k + 1) = 26 \; ; \quad h' = h(k + 1)/2 = 0{\cdot}6 \text{ in.};$$
$$\text{and } D_i'' = D_i\sqrt{(k + 1)/2} = 5{\cdot}46 \text{ in.}$$

Manufacture of Ring-Springs

A steel capable of absorbing the greatest amount of elastic energy must have high yield and impact strengths, so that only spring steels are suitable. Originally, a Si-Mn steel of the type used for railway-carriage springs was chosen ; however, after heat treatment to confer maximum toughness, the carrying capacity of the ring-springs did not prove to be entirely satisfactory, and chromium was added. At the same time, the cross-section of the inner ring, stressed mainly in compression, was reduced, because of the higher compressive fatigue strength of the steel.

In the manufacture of ring-springs, a billet cut from round bar stock is pressed into a ring at 1100°C and rolled into its final shape and size. After inspection, the rings are heat-treated, i.e., quenched in oil and tempered at about 450°C, after which they are mechanically and metallurgically cleaned, and finally greased and assembled as a spring ready for testing. The spring is subjected a number of times to its maximum working load, and a spring diagram is recorded. In this connection, it is interesting to note that the energy dissipated in friction

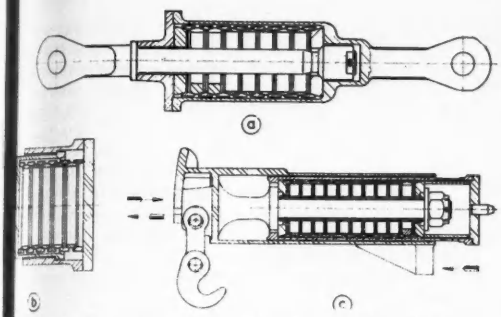

Fig. 7. **Ring-springs used as tension and compression springs.**

during loading and unloading of the spring amounts to about two-thirds of the total work done in compressing the spring. The element is mounted in a hydraulic press under an initial load of 130 tons, and then further compressed under a load increasing up to 200 tons, its length diminishing correspondingly. A safety margin up to about 400 tons is provided for accidental overloading in compression.

Ring-Springs as Fastening Elements

If the radial expansion of the rings is limited or blocked, e.g., by a cylindrical insert, the rings no longer form a true spring, and the axial pressure on the conical faces creates a very high radial surface pressure, so that the spring is converted into a solid clamping or fastening element.

Such an element, consisting of inner and outer rings with cylindrical clamping surfaces and one conical interface (Fig. 4), may connect, for instance, a shaft with a hub. It accurately centres the shaft and hub without the least play, avoids any stress concentration, and effectively seals the connection against the ingress of moisture. Furthermore, the connection can easily be adjusted, in that the shaft and hub may be correctly located without requiring any preliminary fitting. In this application, closed rings are preferable to slotted rings, because (1) the elastic energy in closed rings permits easier disconnection by release of the axial load, (2) only closed rings guarantee an effective seal, (3) slotted rings cannot centre accurately, owing to their axially unsymmetrical stressing, and (4) the edges of the slots may bite into adjacent components, creating stress raisers.

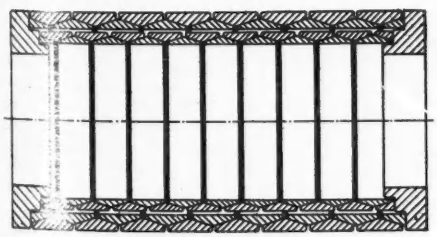

Fig. 8. **Arrangement of ring-springs in parallel.**

Numerous other applications of ring-springs as fastening elements are possible. Thus, for example, an operating lever can be connected rigidly to its shaft by ring-springs, which may be tightened axially by a nut in any desired angular and axial position of the lever, without the fitting difficulties incurred by the use of keys and keyways. Similarly, the cam in Fig. 5 is fastened very simply to its shaft after exact angular positioning. This method of clamping to a shaft is especially advantageous for double helical gears and bevel gears, where exact axial location is of great importance.

The ring-spring is also well known as a fastening and sealing element for high-pressure tubing. In this type of application, the ring must remain elastic, so that the connection can easily be broken, and hence the yield stress of the ring must be appreciably higher than that of the tubing. A large torque can be transmitted by the arrangement shown in Fig. 6, in which two conical wedges press the inner and outer double-conical rings against the shaft and hub. Fitting with accurate positioning is easily accomplished, and the element requires little space.

Applications of Ring-Springs as Springs

Various possibilities of the application of ring-springs as springs are shown in Fig. 7. In Fig. 7a, the outer casing acts as a guide for the ring-spring and affords protection against dirt, etc., while the two slotted inner rings provide a more gradual increase in load. The plunger in Fig. 7b is guided in the casing, and the cover-plate prestresses the spring. Fig. 7c shows a push-pull arrangement often used for mine-tubs.

For especially high loads and large energies, two springs may be arranged in parallel, as shown in Fig. 8. In contrast, one spring with thick rings would carry equally high loads but would have a much lower energy absorption. Springs arranged in series will have composite characteristics, e.g., a flat initial characteristic followed by a steep rise in load.

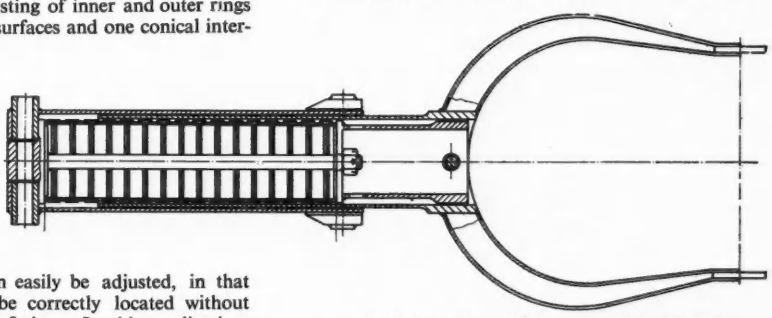

Fig. 9. **Use of ring-springs in an aircraft landing gear.**

The fact that ring-springs have a favourable utilization of metal volume is conducive to a design of minimum weight especially applicable to aircraft construction. Thus, ring-springs are often used as shock-absorbers in the landing gear of aircraft (Fig. 9), where the absorption of energy in friction also plays an important part.

A buffer spring used by the Federal German Railways is mounted as an easily removable self-contained unit prestressed to 1 ton and provided with slotted rings for a slow initial rise in load up to 1·5 tons with a deflection of about 0·25 in. The maximum buffer load is 35 tons with a deflection of about 3 in., and the energy absorbed is then about 50 tons-in.

(*Concluded on page 441*)

U. S. A.

Designing Machine Tools for Automatic Control

By C. B. Sung. (From a paper presented at the *ASME Design Engineering Conference*, New York, May 22, 1957, 40 pages, 13 illustrations.)

(*Concluded from September issue*)

Significance of Servo Performance

For continuous contouring operations, a high-performance machine tool must, during the automatic control mode, be capable of producing high-quality parts under variable cutting loads at fast and uniform feed rates. Also, during the manual control mode, each moving axis must be capable of ready positioning within the desired accuracy with sensitive controls. Indeed, a high-performance machine-tool servo for continuous contouring control represents the most stringent requirements in design. However, it is true that, by using the techniques of programmed slow-down during tape preparation, the severe transient error caused by moving the cutter around sharp corners may be reduced for servos of inadequate performance, although, for intricate contouring operations, it would be somewhat difficult to provide frequent local programmed slow-downs. Even though it is feasible to use the computer to handle the detail programme, frequent slow-downs may often result in a poor surface finish. Furthermore, it would be impractical, as a general rule, to programme the slow-down to compensate for variable cutting loads. This is true even when the part is not intricate. For these reasons, in the manufacture of some contoured parts of desired quality on a machine tool of inadequate servo performance, it may become necessary to use extremely low feed rates and to maintain a light cutting load. Consequently, in automatic control, the performance of the machine, a measure of its productivity, and/or the quality of finished parts may often be limited by that of its servos.

Designing for Adequate Performance

The basic approach in designing a servo of adequate performance is similar to designing a chain, in which the weakest link determines its strength. In somewhat the same way, the element with the lowest band-width plays an important part in determining the band-width of the servo. It is not necessarily true, however, that a satisfactory servo-system will be obtained merely because the performance of all the elements involved is well above the required overall performance. Only the salient points regarding the design of a high-performance machine-tool servo-system will be discussed here.

Servo-Actuators :—

As previously stated, the servo-actuator is regarded as the principal element of the servo-system. If the servo-actuator selected has a very low band-width, it is useless to attempt a thorough scrutiny of the remaining elements in an effort to increase their dynamic response.

For the present discussion, servo-actuators may be classified into two major groups, i.e., electric and electro-hydraulic. For power-control applications in general, an electro-hydraulic actuator has a much higher dynamic performance than an electric actuator of the same capacity and, for controlling a given load, may be designed to have a much higher stiffness and lower inertia. Although there are a few different types of electro-hydraulic servo-actuators, discussion is here limited only to the valve-controlled type, in which a servo-valve is coupled with a hydraulic actuator, as illustrated in Fig. 4. The valve is actuated through a mechanical linkage or hydraulic amplifier by the armature of an electromagnetic device known as a torque motor or force motor, the actuating signal in the form of differential current controlling the direction and displacement of the armature. When the valve is displaced towards the left, it connects one side of the actuator to the fluid at high pressure and the other side to the fluid near atmospheric pressure. Consequently, as a result of differential pressure, the ram is displaced towards the right. Both the inlet and return fluid lines are connected to a hydraulic power supply with a constant pressure delivery.

For controlling rectilinear motion, a hydraulic ram is often used. When a long travel is required, the use of a hydraulic ram may become unsatisfactory if servo performance requirements are relatively high. Because of the long stroke involved, the volume of fluid under compression or expansion is large, and hence the ram loses its stiffness. Although it is always possible to increase stiffness by using larger piston areas, there is a practical limit to both actuator size and the amount of fluid flow involved. For this reason, a rotary hydraulic motor is often used with a lead-screw or rack-and-pinion drive. In this case, the volume under compression is much smaller and is independent of the length of the stroke. For the same reason, it is recommended that the servo-valve should always be closely coupled with the actuator, to minimize the volume under compression, as well as to avoid undesirable line transients.

Machine Structure :—

When designing machine structures for automatic control, the general criterion is a desirable static stiffness with a maximum stiffness-to-weight ratio under various

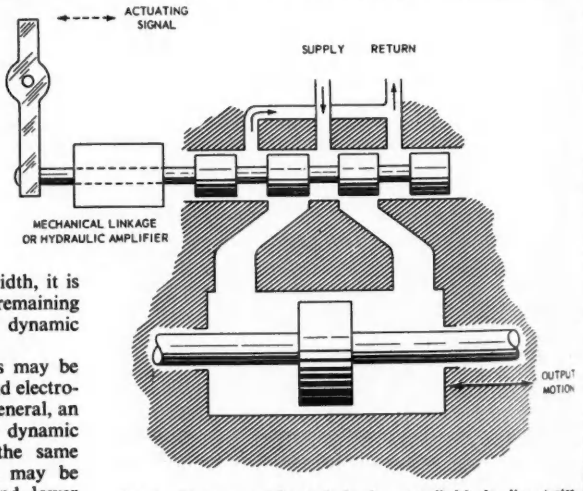

Fig. 4. Arrangement of a typical valve-controlled hydraulic actuator.

orientations of load application. The maximum stiffness-to-weight ratio approach is obviously for high dynamic response. Many machine tools of existing design are quite stiff against flexural loading but weak under torsion. With a slight change in design of machine-member cross-sections, torsional stiffness can often be increased to a level comparable with flexural stiffness, without appreciably increasing weight.

The dynamic response of the machine members outside the loop is often just as critical as those inside the loop, an interesting example being the chain-supported counterweight for a vertical machine slide. This type of counterbalancing usually results in a low natural frequency as a result of high compliance in the chain. Factors such as this can be a major limitation to overall performance. Another example is the machine frame supporting the thrust bearing of a lead-screw, where the frame is usually regarded as outside the loop. Any low resonant frequency in such items, especially when they vibrate in the direction of controlled motion, might easily be a source of difficulty.

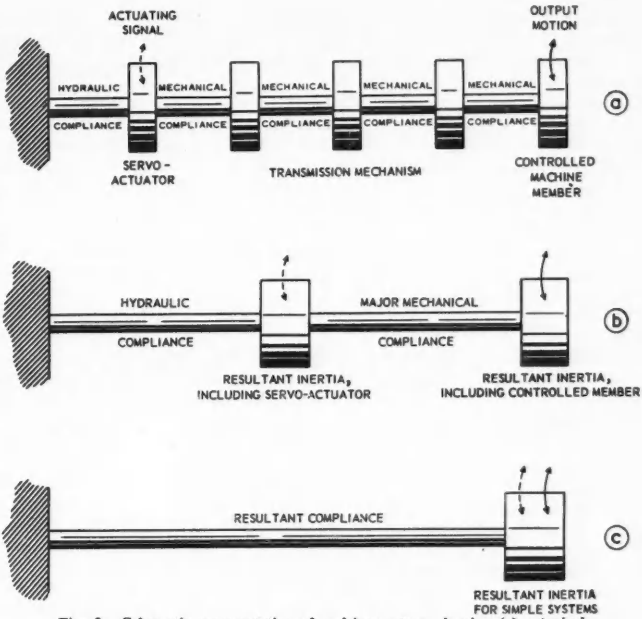

Fig. 5. Schematic representation of a drive system, showing (a) a typical system, (b) a typical approximation, and (c) a simple approximation.

The drive mechanism often attracts the maximum attention of designers. In addition to the problem of backlash, the proper combination or distribution of inertia, compliance, and friction is of vital importance. For a rotary servo-motor controlling rectilinear motion, a major decision is often needed in choosing between a lead-screw and a rack-and-pinion drive. In general, for travels up to 10 or 12 ft, the lead-screw drive is a more favourable choice, since a gear-train of much lower reduction ratio is required for a given maximum motor speed. For travels much longer than 10 ft, the rack-and-pinion drive becomes a more practical arrangement, because the lead-screw drive would result in a lower axial stiffness. This, of course, is only a structural consideration. Other considerations, such as the type of feedback instrument used, unusual speed requirements, the desirability of having a common design for travels of various lengths, space, and cost, may often reverse the decision. In selecting the speed reduction transmission, the irreversible type is generally discouraged, since it introduces a greater chance of causing system instability. Clutches or gear-shifting mechanisms are other items to be discouraged, as they often reduce stiffness and add more inertia to the system.

A brief structural analysis and a survey of available components during the design of the drive mechanism will result in a few alternative arrangements which appear to be equally promising. One arrangement may differ from another in the type or size of servo-actuator, supply pressure used, speed reduction ratio, form of transmission mechanism, type of feedback instrument used, or any combination of these items. It is suggested that preliminary layouts should be made before any detailed analysis is performed.

In carrying out this analysis, it is preferable to relate inertia, friction, and compliance to either the servo-actuator or the controlled machine member. Sometimes, it may become desirable to convert the rectilinear form to an equivalent rotary form or *vice versa*, so that a consistent basis may be established. The purpose of the analysis is to identify weak linkages and to establish the dynamic response of the overall open-loop system. Thus, for every stage, the moment of inertia, compliance, and friction for every gear, shaft, and bearing must be computed. Although the effort may appear tedious in the design of a new system, once the procedure and standard are established, simplified solutions can be readily developed. For example, Fig. 5a is a schematic representation from the servo-actuator to the controlled machine member inclusive, with the damping or friction temporarily neglected. Since the undamped natural frequencies of the lowest modes of motion are of primary interest, this system may be reduced to a much simpler system, Fig. 5b, by an approximation, such as Holzer's method*. By adding the equivalent resultant friction to this simpler system, the dynamic response can be computed by many available methods. If conditions permit, the system may be further reduced to a single degree of freedom, as shown in Fig. 5c. The " hydraulic spring " in most simple systems, such as those directly driven by the servo-actuators, is often the major compliance.

Fig. 5b, in its open-loop form, represents a realistic approximation of many typical high-performance drive systems, without taking into account the effect of load disturbances. For systems using a lead-screw drive, the major mechanical compliance is often the axial compliance of the lead-screw. For this reason, it is often desirable to use a solid lead-screw with thrust bearings on both ends, instead of a hollow lead-screw axially supported at one end. In this way, stiffness can be improved by a factor of four at least, and the natural frequency increased by a factor of at least two. For systems using a rack-and-

* J. P. Den Hartog : " Mechanical Vibrations " ; McGraw-Hill Book Co. Inc., N.Y., 3rd Edition, 1947.

pinion drive, the major mechanical compliance usually exists at the pinion, the pinion shaft, or its bearing. A cantilever type of support should be avoided, whenever possible.

Usually, the best layout can be determined on an open-loop basis, without requiring a detailed closed-loop analysis.

One area that may be easily underemphasized is the gearing, if any, between the feedback instrument and controlled member. In this area, the accuracy and backlash are always emphasized, but not necessarily the dynamic response. Actually, poor dynamic response in the feedback instrumentation can be just as detrimental as that in the power drive.

Friction :—

The viscous type of friction is normally desirable. In actual situations, however, friction is seldom of the viscous type. The typical characteristics are of the dry-friction type, with static or break-away friction much higher than the running or kinetic friction. Consequently, there exists the negative damping phenomenon which is often the source of instability. Negative damping can either be compensated by the addition of effective viscous damping, or minimized by the proper design of bearings. The former is frequently practised in the case of fluid motors with excessive dry friction, while the latter is illustrated by the increasing use of anti-friction bearings.

The use of anti-friction bearings for rotary components is practically a standard design technique. In fact, the low level of friction caused by the use of such bearings is not the only attractive feature, the high magnitude of stiffness and the elimination of backlash by means of proper preloading being other major advantages. The same advantages are mainly responsible for the increasing popularity of ball lead-screws. Although the cost of this type of screw is at present relatively high, drastic reductions in cost can be expected through quantity production.

The application of anti-friction bearings to sliding ways is not necessarily in the same favourable condition. For light-duty or small-capacity machines, this may still be practical and economical. For some large and heavy-duty machines, it becomes impractical to have the desirable precision over the long supporting ways, to ensure a reasonably even load distribution among the balls or rollers. Even if this type of precision can be obtained at the beginning, whether it can be maintained is questionable, because of foundation deflection. The use of purely hydrostatic ways is subject to the same type of considerations. A compromise design may offer an attractive solution, the use of spring-loaded rollers in parallel with sliding ways being an interesting example. The level of friction may be adjusted by changing the amount of preload on the comparatively soft springs. The arrangement is insensitive to the slight waviness of the ways, yet the structure is basically stiff because of the sliding contact of the solid ways. In general, sliding-contact ways still represent the most economical construction. The proper choice and development of bearing material, lubricants, and techniques of lubrication definitely offer many possibilities for improving friction characteristics.

In most cases, provided that the difference between static and kinetic friction can be kept sufficiently low to meet stability and surface-finish requirements, the high Coulomb friction level can always be offset by the use of stiff structures and stiff servo-actuators. It can easily be shown that the stick-slip type of phenomenon can always be accentuated by introducing more flexibility into the driving member.

Backlash :—

To design a satisfactory high-performance servo when the servo has a backlash in excess of the permissible error or surface roughness is indeed difficult. The conservative approach in handling the backlash problem for a high-performance servo is to establish the permissible total backlash according to optimum surface-finish requirements. A simple approximate rule is to limit total backlash, as seen at the machine slide, to less than twice the optimum required surface finish in terms of r.m.s. value of the same units.

For systems using lead-screw drives, ball lead-screws with preloaded double nuts are desirable zero-backlash devices. One method of solving the backlash problem is to eliminate it through preloading techniques, while another is to minimize it by the use of precision gears. The latter is usually accompanied by an adjusting device, such as an eccentric housing for the shaft bearing, so that the gear centre-distance may be adjusted. The precision-gear method is well suited to instrument gearing, since precision instrument gears are commercially available at reasonable cost. This method is also suitable for gear-trains associated with the lead-screw. Since the gear-train provides a speed reduction from the motor to the lead-screw, the stage immediately adjacent to the screw requires the most attention. However, because of considerable speed reduction already in the screw, the precision required in this stage is still reasonable. For a rack-and-pinion drive, the requirements may become too stringent for any practical precision-gear method. In this case, a dual drive with a sufficient amount of preload is often preferred. If designed properly, this method permits the use of gear-trains of commercial grade, with anti-backlash operation and automatic wear compensation.

The Overall System :—

In order to obtain a satisfactory overall system, it would be highly desirable if designers could outline a proper procedure for assembling the critical components and could devise a set of simple tests to ensure that the assembly is properly made. In most cases, dynamic tests on each item, except servo-actuators and the overall assembly, are not required. Usually, there is no need to check the stiffness and moment of inertia of simple machine elements. For many sub-assemblies, especially where preloading is involved or backlash is a critical factor, it is definitely advisable to check their resultant stiffness, friction characteristics, and backlash. Friction and stiffness measurements may be used as an indication of whether a proper amount of preloading is achieved in the anti-friction bearings. The measurements and corrections for each critical individual component and sub-assembly are very helpful prior to the final assembly, since it would be extremely time-consuming to locate and correct the source of trouble if the overall system fails to perform satisfactorily. A simple frequency-response test for the overall system under both open-loop and closed-loop conditions, without using a compensating network, is indeed a useful technique, because it briefly checks servo performance and literally shakes loose any improperly assembled elements. The purpose of these tests should be viewed as an aid to assembling the system, and, in fact, they are a part of the assembly effort. If properly planned and carried out, all these tests for each machine tool can be completed in a week.

Automatic Assembly Line for Needle Bearings

By Ya. M. Yarovinskyi. (From *Stanki i Instrument*, No. 5, 1957, pp. 15-18, 7 illustrations.)

The design of the automatic assembly line for needle bearings described in this article is based on the principle of independent operation of each automatic machine, without dependence on its predecessor or its successor in the line. The entire assembly cycle of a needle bearing is subdivided into individual operations or groups of operations, each operation being accomplished by a separate automatic machine, designed not only as a separate section of the line but also as a self-contained unit. Development work was carried out simultaneously, but the machines were introduced into the line individually, according to their degree of readiness. Thus, the complete line was formed gradually. This method of creating an automatic production line has been fully justified by practical results.

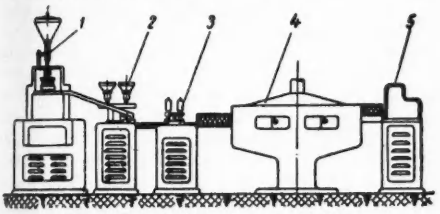

Fig. 1. Layout of complete assembly line.

Fig. 1 shows the layout of the complete automatic assembly line, the individual units of which perform the following functions:—In unit (1), the cage is loaded with needles, and the outer race is pushed over the loaded cage. In unit (2), the two retaining washers are fitted. Unit (3) carries out inspection of the assembled bearing for its internal diameter between the rollers by means of "go" and "no-go" plug gauges. In unit (4), the assembled and inspected bearings are treated for preservation against corrosion, and finally, in unit (5), a third washer* is placed on the bearing, which is then wrapped in paper and counted.

In the automatic assembly unit (Fig. 2), the needles are loaded into a hopper (4) in the needle loading station (1). Reciprocating "stirring" members, actuated by pushers (5), help the needles to enter a tube (6) in steady succession. A lever (7), carrying the end of tube (6), sweeps an arc formed by the pockets of the intermediate needle magazine (8) and fills these pockets with needles. When the time comes for the needles to be fed through the guide-plate (10) into the bearing-cage nests, the intermediate magazine (8) advances until the pockets coincide with the holes in the loading assembly housing, through which the needles slide into the guide-tubes (9) and thence to the guide-plate (10), which, actuated by levers (11), performs a vertical reciprocating motion.

On its downward stroke, the guide-plate (10) lowers with its bottom end face the outer race (12) and uncovers the cage (13). In its extreme lower position the openings of guide plate (10) are located opposite the needle nests in the cage. From the needle loading station (1), the needles are fed to the guide-plate unit (2) at the instant when the guide-plate (10) has taken up its extreme lower position. When the needles have entered the cage nests, the guide-plate starts rising and is followed by the outer race (12), moving under the action of a spring (21). This completes the cycle of the first assembly operation. A turntable (3) removes the race just assembled from the loading position (14). During this motion, a supporting sleeve (15), which slides with its lower end along a cam (16), drops down, and thus the race being processed moves from the loading position (14) to the annular slot so formed. The depth of the slot is equal to the height of the race, and the upper face of the race is then level with the surface of the turntable. During rotation of the table, the race is in the slot and is moved to the loading position of the cage. When the table has taken up this position, the cage being processed is removed from the cage loader (17) with the help of a lever (18) and is set up with its axis on the race axis. When the table moves to the next station, i.e., for loading the cage with needles and assembly of the bearing, the supporting sleeve (15) rises along the cam (16), lifts the race (12), and pushes it over the cage. Thus, the cage advances to this station with the race (12) pushed over it. In its needle loading and assembly position, the cam (16) has a bore in which a spring-loaded plunger (19) is situated. Thus, as described above, whilst the turntable is in this station, the guide-plate (10), under the action of the spring and of the levers (11), removes the race from the cage and again pushes it over the cage after this is loaded with needles. After assembly, the turntable transports the assembled bearing from the assembly station and ejects it into a chute (20), along which the assembled bearing slides onto the loading chute of the next automatic machine.

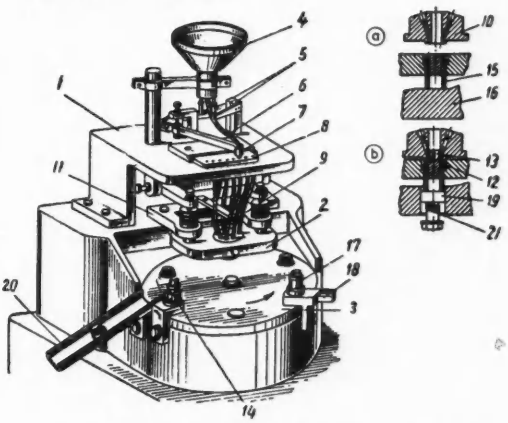

Fig. 2. Unit for assembly of needles and outer race.
(a) Race loading station. (b) Needle insertion station.

The automatic machine for the fitting of the two retaining washers (Fig. 3) functions as follows:—The washers are heaped into hoppers (1), whence, by means of a disc provided with pockets, and rotated by a ratchet mechanism (2), one washer per disc in every revolution of the control camshaft is fed from chutes (3) to guide-tubes (4). The individual washers are ejected from the tubes (4) by appropriate slides onto the guides (5). Whilst moving along the guides each washer is oriented to face the bearing with its land downwards. If the washer rolls along the guide with its land facing in the

* As no specifications of the bearings concerned are given in this article, the purpose of this third washer is not clear. It does not, however, appear to be an integral part of the bearing. *Editor, E.D.*

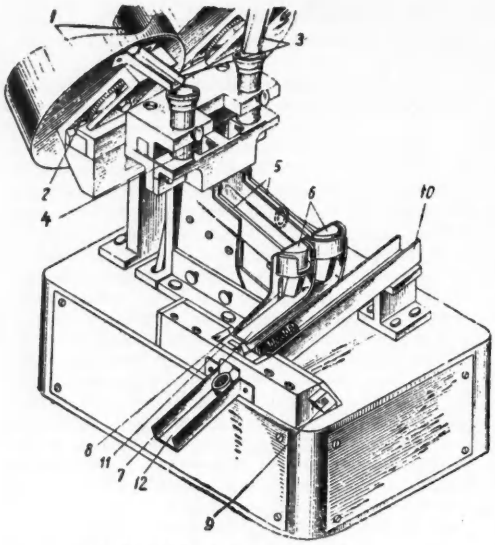

Fig. 3. Unit for fitting retaining washers.

wrong direction, when it has reached the section in which the guide has a bottom width equal to the width of the cylindrical part of the washer, it will slide along this narrow guide and proceed to a reversing device (6), whence it emerges with the appropriate orientation, i.e., with its land downwards, onto the corresponding chutes (7). If the washer slides down the guide with its land facing in the correct direction, once it has reached the narrow part of the guide it loses its support, drops down, and emerges from an opening onto the corresponding chute (7), also with its land down, as required by the design of the bearing. Fitting of the washers in the bearing proceeds as follows:—From the right-hand hopper, the washer being processed is fed by the corresponding slide onto the lower chute (7), whence it proceeds to the bottom of the fitting unit (8). When the lower washer has taken up its correct position, a slide (9) advances the bearing from a chute (10) over the lower washer. During this motion, a spring-loaded support (11) is pushed to the left. When the bearing has taken up its extreme position, a slide in the washer feed unit (2) pushes the corresponding upper washer onto the guide, along which the washer proceeds to the fitting unit (8) and covers the particular bearing being assembled, which has been advanced to this position by the slide (9). After fitting the upper washer, the slide (9) moves to the right and the support (11) pushes the bearing with the fitted washers into a chute (12), along which it advances to the subsequent automatic machine. Sequence control of all the motions of the unit and components of the machine is ensured by a camshaft not shown in the drawing.

The automatic machine for the inspection of assembled bearings (Fig. 4) performs the checking of the diameter between the generators of the needles (held to an accuracy of 10 microns). The assembled bearing is conveyed along a chute (1) by a rubber belt into the extreme left-hand position, from which it is moved by a slide (2) to the right into the first measuring station. In this station, inspection of the assembled bearing is carried out with a " go " plug-gauge. When the inspected bearing has been positioned at the measuring station, a moving plate (3), which carries a holder to which the gauge is fixed, is lowered and the holder descends under the effect of a weight (4). Thus, the " go " gauge enters the bearing, and, if the bearing is correct, it drops to the full depth of the bearing. During this motion, a stop (5), fixed to the holder, presses against a dog (6), dropping and locking a spring-loaded slide (7), which is held back in the withdrawn position by the corresponding cam of the control shaft. When the gauge holder with its weight and gauge is raised by means of the plate (3), the cam which arrests the slide (7) depresses it and allows it to move to the left under the effect of the spring, except that it is held back by the dog (6), which presses against a nose (8) formed in the slide (7). The bearing is now pushed by the slide (2) to the second measuring station, where it is checked by the " no-go " plug-gauge. After completion of the measuring cycle, the slide (7) is moved to the right by the control-shaft cam. During this motion, the nose (8) of slide (9) raises the dog (6) and returns it to its initial position, in which it is retained by the friction of its side surfaces. If, in the first measuring station, the bearing does not admit the entry of the " go " plug-gauge, its holder will be supported at a certain height by the bearing. In this case, the stop (5) will not touch the dog (6). The holder, together with its gauge and weight, will be raised by the plate (3). The slide (7), depressed by the control-shaft cam, is raised to the left by the action of the spring and ejects the bearing into a side channel. Inspection by the " no-go " plug-gauge proceeds in the same manner as inspection by the " go " gauge. Correct bearings are guided by a slide (9) into a side channel and thence by a conveyor to the next machine in the line. Rejected bearings are pushed out by the slide (2) onto a straight channel and fall into a scrap bin.

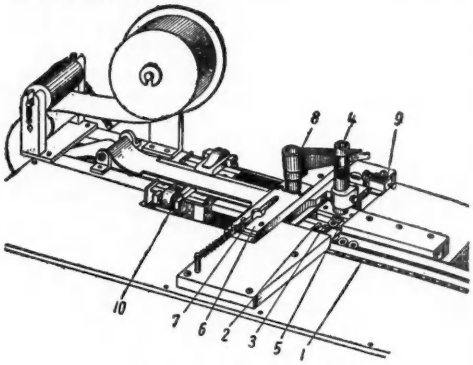

Fig. 4. Unit for inspection of assembled bearings.

The design of the unit for the protective treatment of bearings is shown in Fig. 5. After passing through the inspection machine, the bearing is fed by a conveyor belt along a channel (1) to a slide (2), whose width corresponds to the width of two races. Thus, each stroke of the slide (2) feeds two bearings to the rail (3) of the slide (4), which, performing a reciprocating motion, feeds the pair of bearings by means of the rail (3) into a pocket (6) of the first disc (5) at the instant when the discs have rotated by one pitch and are held in the loading position.

The treatment process consists of dipping the bearing in four baths. In the first bath the bearings are washed in a hot solution of sodium carbonate. In the second bath this solution is evaporated in hot oil, in the third bath final evaporation is carried out in hot Vaseline, and

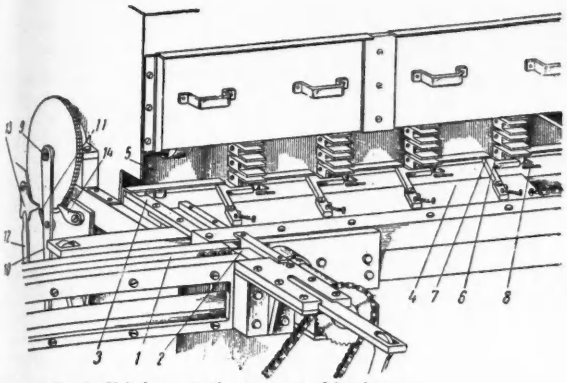

Fig. 5. Unit for protective treatment of bearings.

in the fourth bath the bearings are coated with hot Vaseline. After completion of the appropriate treatment, the bearings in the pocket are transported by an arm (7), whose motion is controlled by spring-loaded stops, into the pocket of the following disc. The bearings which have passed the treatment in all discs are moved by the last arm to a conveyor which feeds the treated bearings into the last automatic machine of the line.

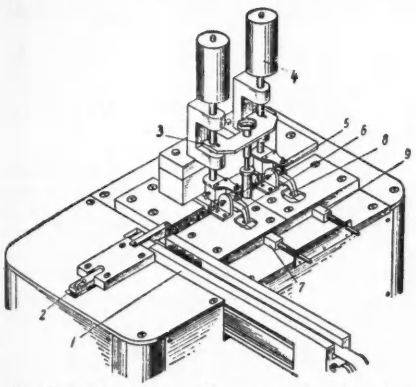

Fig. 6. Unit for final assembly and wrapping of bearings.

The mechanism of rotation of the discs is arranged as follows:—The discs (5) are rigidly attached to a shaft (9), which also carries two ratchets with teeth facing in opposite directions, 90 pockets being attached to each disc. Periodically, after 2·5 sec, the shaft with the discs turns by 4 deg. and brings one pocket into position for the unloading of treated bearings and the loading of untreated bearings. The rotation of shaft (9) with its discs is effected by means of a lever (10) to which a dog (11) is attached. Performing a rocking motion under the action of the appropriate cam of the control shaft, lever (10), by means of dog (11) and the outer ratchet, rotates shaft (9) by 4 deg. Lever (12), under the action of its appropriate control-shaft cam, has previously been disengaged from the inner ratchet, and holds a dog (13). Dog (14) serves to prevent the rotation of shaft (9), when dog (11) moves into its initial position.

The automatic machine for laying down the third washer and wrapping the bearing in paper (Fig. 6) completes the automatic line. With the aid of a chain conveyor (1) the bearing is transported from the treatment unit as far as stop (2), and thence is led by a slide (3) to the station for laying down the third washer. With the help of a special mechanism not shown in the drawing, the third washer is withdrawn from a feed unit (4) and put on the bearing, after which a slide (5) feeds the bearing into the wrapping unit (6).

Wrapping is carried out in two operations, in which the first envelops the bearing in paper and the second packs the free ends of the paper into the bore of the bearing. In the first operation, the paper feed unit (10) pulls a certain length of paper over the bearing, which has been advanced by the slide (5), and which is then lifted by a plunger. In the second operation, the bearing enveloped in paper is moved to the left by a slide (7). During this motion the open ends of the paper are bunched together and in the extreme left-hand position are rammed into the bore of the bearing. After this operation, the wrapped bearing is pushed by the next bearing into a chute (8). The automatic line is fitted with a counter (9) which is actuated only after the passage of a bearing through the last unit, the counter mechanism being connected to an interlocking device, which controls the paper feed unit (10).

Parallel with the development of the automatic assembly line and the transporting devices used, the economic aspects of the automation of bearing assembly were investigated. The most important, indeed the decisive, element in the cost of assembly operations is that of labour. In this connection, assuming the cost of labour for manual assembly to be 100%, it has been found that the comparative cost using unit (1) only is 92·1%, and using units (1) and (2) only 87%. Adding unit (3) to the assembly line reduces the cost to 63·2%, and unit (4) to 55·2%. With all five units in the complete assembly line, the cost is reduced to 48·5%.

Expenditure on gauges is considerably reduced, because their life is considerably increased. Auxiliary materials also become cheaper, since, during automatic assembly, washing of the bearings in petrol before their anti-corrosion treatment is eliminated.

It is stated that the automatic production line pays for itself within a year.

The Use of "Ring-Springs" as Fastening Elements and in Other Applications

(*Concluded from page 435*)

Among other applications, ring-springs are used as buffers and overrun devices for cranes. Thus, for instance, the overrun shown in Fig. 10 works first as a buffer

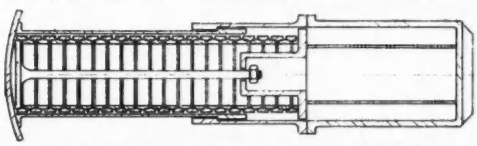

Fig. 10. Use of ring-springs as an overrun safety device.

with a deflection of 6·75 in., and then as a safety device, using an expendable tube which is deformed plastically by buckling and absorbs a large amount of additional energy.

HOLLAND

A High-Precision Lathe Headstock

By L. M. LEBLANS. (From *Philips Technical Review*, Vol. 19, No. 2, 1957/58, pp. 68–69, 2 illustrations.)

LATHES for high-precision machining in a direction perpendicular to the axis of rotation are generally available, and on special toolroom lathes shafts may be turned to a diameter tolerance of a few microns, whilst local surface roughness may even be reduced to 0·5μ. When, however, a lathe is used to machine flats or profiles on end surfaces, e.g., on plastic lenses, accuracy in a direction parallel to the axis becomes of importance. This accuracy, which is not very critical for ordinary applications, is mainly dependent on the thrust bearings of the lathe spindle.

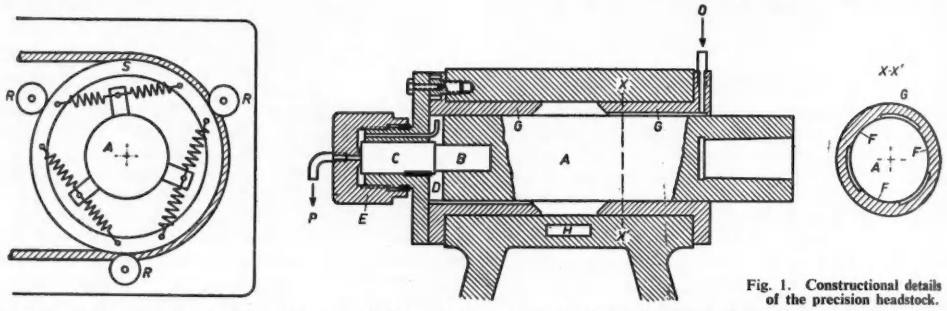

Fig. 1. Constructional details of the precision headstock.

With other machine tools, such as grinding and drilling machines, it may also occur that, for obtaining extremely smooth surfaces, a highly accurate thrust bearing is desired. Adequate results for this purpose may be obtained with conical slide-bearings, but a fairly large tolerance must be observed to allow for changing loads. Clearly, this affects the accuracy attainable.

A bearing free from this drawback and ensuring a very high degree of axial and radial accuracy has been developed by the Eindhoven Research Laboratories. Its construction is shown in Fig. 1, in which a steel spindle *A* runs in a bronze bearing block *G*, which has three bearing surfaces *F*. The end of the main spindle, which is accurately supported in a radial direction by the bearing, is fitted with a piece of " improved wood " *B*. This wooden member rests against a stationary metal thrust block *C*, whose front surface has been lapped plane and perpendicular to the main spindle with a high degree of accuracy. The main spindle is pressed against the thrust block with a constant force, owing to the fact that a constant sub-atmospheric pressure is maintained in the closed compartment *D* in which this contact takes place. The thrust block *C* can be axially displaced by means of a micrometer screw *E*. In this way, the workpiece on the main spindle can be displaced over an extremely small distance (the cutting depth) with respect to the tool. Evidently, the position of the tool in an axial direction must also be fixed with great precision, but this requirement can be readily satisfied.

The low pressure in compartment *D* also sucks in an ample flow of oil along the main spindle, the oil entering at *O* and being discharged at *P*. This flow of oil ensures the efficient lubrication essential for very accurate radial support. Both the steel spindle *A* and the three supporting surfaces *F* of the bronze bearing block *C* are accurately lapped to size with a tolerance of only about 1μ. This means that a temperature drop of 5°C would cause the spindle to seize because of the difference in coefficient of expansion between the two materials. This is avoided by keeping the whole bearing at a constant temperature of about 30°C by means of a heating element *H*. The enforced oil flow prevents any excessive local overheating of the sliding surfaces, eliminating the possibility of increased play.

The spindle should be driven with the greatest uniformity, avoiding any vibrations in the drive. The pulley *S* is therefore not fitted rigidly to the spindle, but coupled to it via six steel springs. The pulley is not supported by the spindle bearing, but on rollers *R*.

The axial accuracy attainable with this construction can be deduced from Fig. 2, which is a photomicrograph of the surface of a flat disc machined on a lathe equipped with this headstock. A diamond-tipped tool with a round tip of radius 200μ was used. The lateral displacement of the tool was 9μ per revolution. The finished surface thus consists of adjacent grooves 9μ wide and with a depth of about 0·05μ. A close examination of this photomicrograph shows that the width of the groove never varies by more than about 5%. This means that, during the machining period, the axial displacement of the lathe spindle relative to the tool did not amount to more than 10% of the groove depth, i.e., less than 0·005μ.

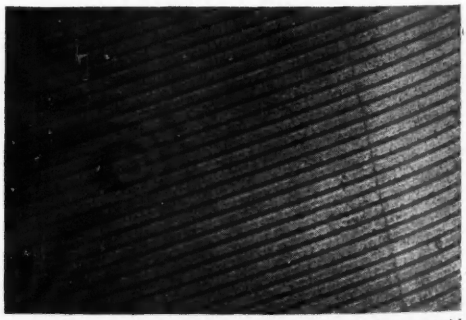

Fig. 2. Photomicrograph of the surface of a disc of plastic material machined flat on a lathe fitted with the precision headstock. (×250)

The same lathe was used for machining a cavity resonator for 8·75 cm wavelength for high-precision measurements of the dielectric losses in solids. It was essential to keep local unevenness of the wall, bottom, and cover of the cavity as small as possible with respect to the penetration depth of the high-frequency currents, i.e., about 1μ for the wavelength in question. Measurements of the quality factor of the cavity resonator confirmed that the unevenness of the machined surfaces was indeed very small with respect to penetration depth.

Simplified Construction of Mixers and Stirrers on the "Convergence-Divergence" Principle

By Dr. M. S. Frenkel.*

In our issues of November and December, 1956, Dr. Frenkel discussed his principle of "Convergence-Divergence" in mixing and other applications and as a basis for quantitative and qualitative mixing, giving examples of basic constructions, in which use was made of two rotating components. In this article he considers a simplified development of mixers, etc. constructed on the "Convergence-Divergence" principle, in which only one component rotates, without, however, detracting from efficiency in a wide range of applications.

The principles and basic constructions of mixers, extruders, crushers, etc. developed on the principle of "Convergence-Divergence" (the *C-D* principle) have already been referred to in the literature[1-9]. These basic constructions have since been confirmed experimentally in many different applications, e.g., as dynamic sealing glands, as crushers for coal, limestone, etc., and as continuous mixers and extruders for a wide range of materials, including viscous and fatty substances and for mixing differently coloured clays and for dispersing carbon black to a completely uniform resulting colour.

The construction treated in this article is covered by patent applications and constitutes one of a series of simplified constructions derived from the *C-D* principle and covering a comprehensive field of practical applications, including a continuous mixer or extruder, a batch mixer, a stirrer, and heat-exchange mixers and stirrers, suitable for a wide range of conditions.

In the original mixers designed on the *C-D* principle, both the inner and outer screw components rotate in opposite directions and have opposite-handed helical threads, with a complementary variation in groove cross-sections between maximum and zero areas, the maximum cross-section of the one groove facing the zero cross-section of the other[1-5]. The opposite rotation of both screw components produces, with material transfer between the components, a forward driving force from each component and, in addition, creates vortices in the groove of each screw[2,4], while the interpenetration in the transit zone and in the grooves themselves provides thorough mixing of the entire throughput. The conical interface between the screw components, allowing relative axial displacement, enables the clearance between the screws to be adjusted, permitting control of the intensity of mixing and other effects[1,2,4,5].

In the simplified form of construction under consideration, only one of the components, i.e., the inner component, is rotated. Admittedly, in some applications, such as heavy crushing, the use of two rotating components is usually essential, as material transport may otherwise be greatly impeded or even halted completely, but in many other applications, including mixing and stirring, the use of only one rotating component can be applied with complete success to many materials, resulting in simplified construction without, however, any apparent loss in efficiency.

In the case of only one rotating component, helical (or otherwise curved) grooves in the non-rotating component would not contribute to forward motion of the material being treated, as they would do in a rotating component, but would merely exert considerable resistance to transport of the material, thus limiting throughput and the attainment of any required extrusion pressures at the outlet.

Consequently, to reduce this resistance to a minimum, the grooves in the non-rotating component should be formed as paths of least resistance, i.e., preferably extending along the straight generating lines of the conical interface. As a result, the rotable inner component with its helical (or spiral) thread produces a forward driving force, which is applied to the whole of the material being treated. In addition, the reduction in resistance of the non-rotating component resulting from straightening the grooves removes any difficulties regarding throughput with a wide range of materials. A further advantage is that the forward driving force of the lands of the rotating screw is increased, as the lands of the vanes forming the grooves of the non-rotating component are directed straight along the conical interface. The apex angle of the conical interface may, depending on the application, have any value between 0 and 180 deg. In the latter extreme case, the grooves become radial (Fig. 4).

It should be understood that, in accordance with the *C-D* principle, the grooves of the non-rotating component still vary in cross-sectional area between maximum and zero values, complementary to the variation of the grooves of the rotating screw, providing intensive intermixing, in which every particle of the throughput is successively involved. Moreover, quite apart from the fact that the use of straight grooves in the non-rotating component greatly simplifies manufacture and cleaning, this type of construction enables any required extrusion pressures to be produced for a given throughput, these quantities being adjustable by varying the speed of the rotating component and the clearance.

Examples of Applications

This simplified form of construction lends itself to a wide range of applications. It is flexible, since, as already mentioned, the conical interface can be made with any apex angle between 0 and 180 deg. Thus, for example, it can be applied with complete success to continuous mixer-extruders (Fig. 1), batch-mixers (Fig. 2), and stirrers (Figs. 3 and 4), as well as mincers, kneaders, etc.

In the design shown in Fig. 1, material entering through the funnel (6) is transported into the feed section (5) of the rotatable inner screw component (1); in the material-transfer section (7) of both components, owing to the gradual reduction in the cross-sectional area of the grooves of the inner screw and the complementary increase in cross-section of the straight grooves of the non-rotating outer component (2) between maximum and zero values, all the material is transferred to the outer component, and every particle of the throughput is obliged to pass through the transit zone, i.e., the conical interface between the two components. Where required, provision for heating and/or cooling can be made in one or both components. The number of grooves in the non-rotating component can vary within wide limits.

* Consulting physicist and engineer.

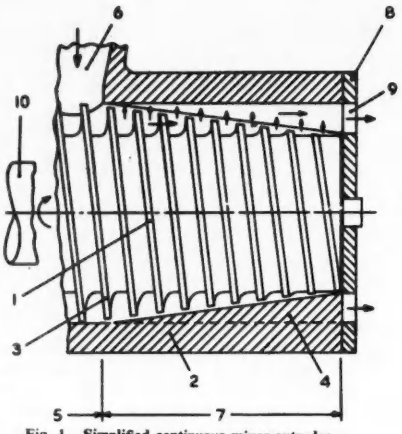

Fig. 1. **Simplified continuous mixer-extruder.**
(1) Rotating inner screw component.
(2) Non-rotating outer component.
(3) Helical thread on inner component.
(4) Straight vanes in outer component.
(5) Feed section of inner screw component.
(6) Feed funnel.
(7) Material-transfer section of both components.
(8) Breaker-plate.
(9) Holes in breaker-plate.
(10) Drive shaft.

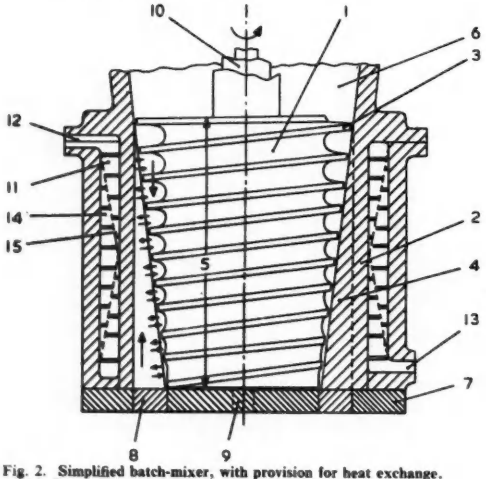

Fig. 2. **Simplified batch-mixer, with provision for heat exchange.**
(1) Rotating inner screw component.
(2) Non-rotating outer component.
(3) Helical thread on inner component.
(4) Straight vanes in outer component.
(5) Material-transfer zone between components.
(6) Feed funnel.
(7) Bottom cover of housing.
(8) Outlets, with plugs or valves.
(9) Alternative central outlet.
(10) Drive shaft with provision for internal heat exchange.
(11) Annular heat-exchange passage.
(12), (13) Inlet and outlet for heat-exchange medium.
(14), (15) Opposite-handed helical vanes in annular passage.

The example illustrated in Fig. 1 shows material transfer from the inner to the outer component only, with outlets (9) through a breaker-plate (8), which may, however, be replaced by an extrusion head, if desired. An additional section providing a return of material transfer from the outer to the inner component may also be incorporated, completing the mixing cycle.

In the example of a batch-mixer shown in Fig. 2, the material is transported downwards in the helical grooves of the inner component (1) and, as it is unable to flow out through the closed bottom (7), it is forced to flow upwards and circulate, as a result of the pressure difference generated in the straight grooves of the non-rotating component (2). Since the material in both components thus flows in the directions of decreasing cross-section of the grooves, there is in this case a simultaneous mutual material transfer between the entire inner and outer components, providing even more intensive and thorough intermixing in the material-transfer zone (5), as indicated by the arrows, than occurs with the one-way transfer in Fig. 1. When the mixing operation is completed, the material is removed (by the pumping action of the rotor) through openings (8) provided with suitable valves.

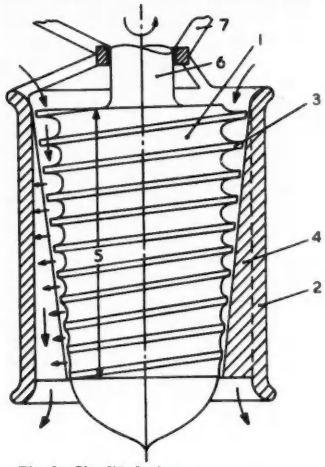

Fig. 3. **Simplified stirrer.**
(1) Rotating inner screw component.
(2) Non-rotating outer component.
(3) Helical thread on inner component.
(4) Straight vanes in outer component.
(5) Material-transfer section.
(6) Drive shaft.
(7) Frame for suspension in vessel.

The example shown in Fig. 2 incorporates a heat exchanger with guide-vanes (14) and (15), also constructed on the *C-D* principle, in the annular heat-exchange passage (11). These guide-vanes form opposite-handed helices, which vary in the cross-sectional area of their grooves between maximum and zero in a complementary manner. When the heat-exchange medium is pumped through the annular passage (11), vortices are produced in the grooves formed by the helical vanes, these vortices being transferred layer by layer into the opposite groove. The thinness of these layers depends on design. Each layer individually contacts the heat-transfer wall in a completely orderly manner, as is essential for maintaining a high temperature difference between the contact layers over the total area of the heat-transfer wall. As a result, optimum heat transfer is ensured, as no layer can escape contact with the wall or can have more contact with the wall than any other layer, thereby eliminating the detrimental effects of indiscriminate turbulence.

Fig. 3 is an example of this simplified form of construction applied to a stirrer, which, in addition to thorough intermixing of all particles, provides a vigorous cycling action of the medium in the pan, still, or other vessel in which it is used.

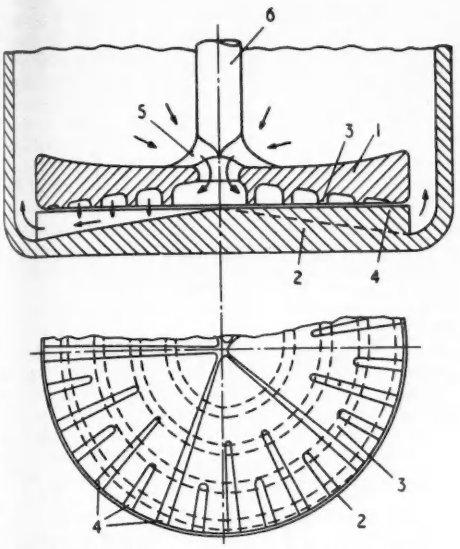

Fig. 4. Stirrer with flat interface operating against bottom of vessel.
(1) Rotor.
(2) Stationary vessel.
(3) Spiral thread in rotor.
(4) Straight (radial) vanes on bottom of vessel.
(5) Entry into rotor.
(6) Drive shaft.

Fig. 4 shows an example of a stirrer with a flat interface, i.e., with an apex angle of 180 deg., in which one component rotates against a non-rotating component formed by the bottom of the pan. This construction not only produces thorough intermixing and circulation but makes possible extremely efficient and controllable heat transfer through the bottom of the vessel, thus permitting processing of heat-sensitive materials. Incidentally, this design with a flat interface may be incorporated into the mixer shown in Fig. 2, the bottom of the inner screw component (1) in Fig. 2 in this case being formed as a spiral, and the internal surface of the bottom cover (7) being provided with radial vanes or opposite spiral grooves, with complementary variations in groove cross-sections, as in Fig. 4. In this way, additional surface can be used for intermixing, and discharge can be effected through the central opening (9) in Fig. 2, fitted with a suitable valve.

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FRANCE

Water or Steam Injection in the Combustion Chambers of Gas Turbines

By P. CHAMBADAL. (From *Chaleur et Industrie*, Vol. 38, No. 384, pp. 173–186, 9 illustrations.)

In its present state of development, the simple open-cycle gas turbine can be regarded as the most suitable type of heat engine for peak-load power requirements in distribution networks. Peak-load power plants are put into operation not only when the demand for power is high but also in the case of failure of normal generating plants or power-transmission systems. Such stand-by units, therefore, are selected mainly on the basis of their ability to fulfil the conditions of rapid starting and low capital cost per kilowatt installed. Since these plants are required to operate for only a limited number of hours per year, fuel cost is a minor factor in their annual operating costs. Thus, the maximum attainable efficiency is less important than low capital costs for such applications.

Particularly economical operating conditions are obtained with the following solution, which has been adopted by the French Electricity Authority[1,2]:—Under normal conditions, the synchronous generator of the peak-load plant is used to supply reactive power (up to 10,000 kVA) to the grid. When peak-load requirements have to be met, the generator is coupled to the shaft of a gas turbine with a capacity of 6000 kW, and supplies useful power to the grid during the required period. Five such installations have been operating in France since 1953; ultimately, their number will be considerably increased.

The purpose of this article is to examine the possibilities attainable by using water or steam injection in gas turbines in installations required for intermittent or for continuous operation. Before doing so, however, it will be of interest to consider the present position of gas turbines in electricity production.

Gas Turbines in Electric Power Stations

According to statistical information published in the U.S.A.,[3] the number of gas turbines for stationary installations under construction or in service increased from 148 in 1952 to 413 in 1956. It can therefore be said that the gas turbine is in an "aggressive" phase of development. The average power rating of these machines is only about 4400 kW; the largest unit, however, will develop 40,000 kW and is being incorporated in an installation for the Västervik power station in Sweden.

The 413 gas turbines mentioned above include 390 which are specifically used for electricity production or as compressor drives. After subtracting those units coupled to compressors not incorporated in electrical installations,

the gas turbines operating in steelworks and supplied with blast-furnace gas, and those combined with free-piston generators[4], it is found that there are roughly about 160 gas turbines provided with a rotary compressor (usually of the axial type), operating on liquid fuel or natural gas and serving for electric power generation.

Although these gas turbines are considerably different in their arrangement and thermal cycles, they show a definite trend towards simplified designs.[2] Some recent units include air cooling during compression and gas reheat during expansion, to obtain high specific outputs. These modifications, while improving the efficiency of the machines, do not increase the capital cost per unit of power generated.

The decision to use waste-heat recovery, however, should be taken only after making a careful assessment of the economic aspects, i.e., initial cost, fuel, maintenance, extent of the slight reduction in useful power developed, etc., so as to determine the maximum effectiveness of the heat exchanger and its optimum surface. The latter is evidently related to the expected period of operation of the machine per year, since for short periods the presence of the heat exchanger would only increase the cost of the current generated. Moreover, in areas where fuel is plentiful and inexpensive, an exhaust heat exchanger is not employed, even in plants with a high number of annual operating hours.

Of the 160 gas-turbine plants mentioned above, only 40 are provided with waste-heat recovery, indicating that in the great majority of cases the gas-turbine plant has been intentionally designed with a view to reducing investment costs to a minimum, accepting the expense of somewhat increased fuel consumption. For a certain range of power outputs, the gas turbine without an exhaust heat exchanger is the least expensive of all heat engines, so that it amply justifies its use in all cases where fuel costs are a minor consideration.

Water or Steam Injection ahead of the Gas Turbine

Various suggestions have been published in recent years on the introduction of water or steam in the gas supplied to the turbine. These should not be confused with another solution, which is to inject water in the various stages of the air compressor.[5] This latter possibility is intended to increase the overall efficiency of the turbine by cooling the air, during compression, by means of a continuous addition of water ; it does not appear superior to the usual method in which air is passed through surface coolers with water circulation. The addition of water downstream of the compressor, however, is considered as a means of increasing not so much the efficiency of the machine as its specific power capacity. The reduced cost per unit of power produced is always associated with some decrease in efficiency, but the final result may be favourable when the fuel cost is a secondary factor, as in peak-load generating plants.

A cycle of this kind is shown in its simplest form in Fig. 1. Air from the compressor (1) receives at (2) a certain quantity of vaporized water, and the mixture enters the combustion chamber (3), into which fuel is introduced by a burner (4). Fuel flow is adjusted so as to ensure complete evaporation of the water, while the gas and steam mixture is raised to the required temperature. This mixture is expanded in turbine (5) and then exhausted into the atmosphere. The excess of the work done during expansion over that required for compression is transmitted to the generator (6). It may be noted that the water, instead of being introduced ahead of the combustion chamber, could be injected directly into this chamber or even after it.

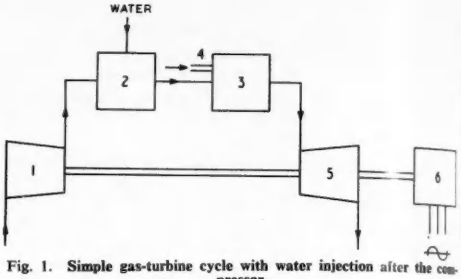

Fig. 1. Simple gas-turbine cycle with water injection after the compressor.

The addition of water thus permits an increase in the work performed during the expansion process, i.e., an increase in useful power, without raising the installation costs appreciably. However, fuel consumption is increased because, whatever the thermal efficiency may be of a simple-cycle gas turbine, it is generally higher than that of a steam generator with a back-pressure turbine operating with the same initial temperature and expansion ratio. The additional energy provided by the steam used in turbine (5) is therefore more expensive than that due to the expansion of the gas, and consequently raises the specific fuel cost.

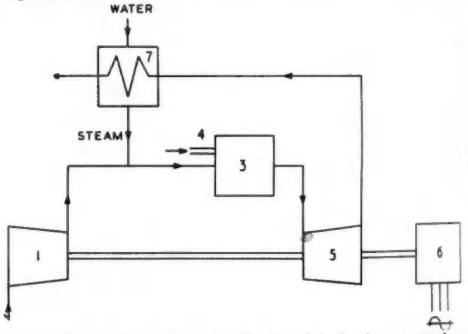

Fig. 2. Simple gas-turbine cycle with steam injection from a waste-heat boiler.

The injection of steam, instead of water, into the compressed air gives approximately the same variations in useful power and fuel consumption. However, some of the fuel required for steam generation can be saved by using a waste-heat boiler ((7) in Fig. 2). This boiler is heated solely by the gases and steam from the turbine exhaust. Its presence increases slightly the load loss in the gas cycle and puts up the cost of the installation, but the specific cost per kilowatt installed is still lower than that of a gas turbine without water injection and, moreover, specific fuel consumption is also reduced.

The basic cycles in Figs. 1 and 2 are, of course, particularly simple and can be completed or modified by various methods, as outlined in the following survey of recent suggestions on this subject.

(*a*) In connection with gas turbines built by the General Electric Co., U.S.A., it has been estimated by Marsh and Wright[6] that, with an arrangement basically similar to that in Fig. 1, the addition of 0·1 kg of water per kg of compressed air would permit a 40% increase in useful power (from 16,500 to 23,000 kW), while reducing by about 24% the cost of the turbo-alternator group per kilowatt installed, i.e., from $76 to $58. However,

specific heat consumption would increase by approximately 23%, i.e., from 4120 to 5050 kcal/kWh) and overload operation with water injection would be limited to 1000 hours per year.

If, instead, steam injection were used in a cycle such as that in Fig. 2, the group would be capable of developing 21,100 kW continuous power, and on a 1000-hr overload rating with added steam would be 22,700 kW. These figures would be obtainable at a cost of $65 per kW installed i.e., 14% below that of a conventional unit, with a specific consumption of 3680 kcal/kWh, i.e., 10% less than without water or steam injection.

(*b*) In a futher investigation, the General Electric Co. has used water injection in a cycle similar to that in Fig. 1, but with the air and water mixture passing through a heat recuperator before entering the combustion chamber.[7] The water in the mixture is converted into steam, lowering the temperature of the mixture (from its value of about 260°C without water injection) and increasing the temperature difference between the heating medium and the mixture in the heat exchanger.

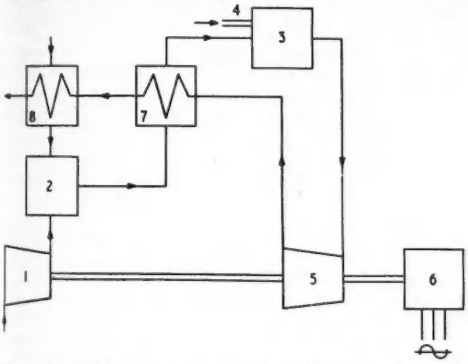

Fig. 3. **Gas-turbine cycle using a recuperator and a preheater for water injection.**

(*c*) Another water-injection arrangement, recently described by White[8] and shown schematically in Fig. 3, comprises two heat exchangers traversed by the combustion products and the steam from the exhaust of the gas-turbine (5). The first is a recuperator (7), which heats the mixture of air and steam from the evaporator (2), whereas the second is a preheater (8) for the injected water. With 5% water added to the weight of air from the compressor discharge, the useful power is increased by 20% ; with up to 10% water, the further increase in power is 4·5% for each percent weight of water injected.

(*d*) A large number of cycles are described by Miller in U.S. Patents Nos. 2,678,531 and 2,678,532. For a system similar to that in Fig. 2, but with a waste-heat boiler (2) which incorporates a water preheater located in series with the evaporator section, the main results obtained are as follows :—By adding 0·2 kg of steam per kg of air from the compressor discharge, the useful power is increased by 97% (from 6225 to 12,260 hp, with an air consumption of 40·8 kg/sec), while efficiency is improved by 36% (from 18·2% to 24·8%, with methane used as fuel). The cost of the installation, however, increases by some 44%, whereas the cost per kilowatt decreases by about 27%.

Patent No. 2,678,531 also compares these results with those of a conventional installation operating with heat recovery but without steam injection. The heat exchanger (with a surface of 4650 m²) increases the load losses of the cycle, so that the useful power is reduced to 5630 hp, while the thermal efficiency is raised to 25%. It thus appears that the use of the waste-heat boiler in the steam-addition process (Fig. 2) gives the same efficiency as the heat exchanger in the conventional process, while increasing the useful power by 118% ; at the same time, the cost of the plant is increased by only 20%, so that the steam-addition process lowers the cost per kilowatt by 45%. Other boiler and heat-exchanger arrangements are also discussed in a paper by Miller.[9]

(*e*) The possibility of having a peak-load power plant similar to that in Fig. 2, in which the boiler can serve for industrial heating purposes when not required for electricity production has been considered by di Zenete[10].

(*f*) Other interesting plants have been described or suggested by Mordell[11,12]. In an installation at McGill University, Montreal, combustion takes place at atmospheric pressure and the heat is transferred to the compressed air by means of a heat exchanger. The turbine thus receives pure air, which, after expansion, is used as an oxidant in the combustion chamber. Mordell considers the possibility of utilizing the residual heat of the combustion gases for steam generation. This steam added to the compressed air would increase the useful power by 50% (to 7500 kW) while raising the thermal efficiency from 21·2% to 24·3%. As a result, the cost of the plant per kW generated would be reduced by 25%.

(*g*) The Brown Boveri Company in Switzerland recently published the results of operating a 12,000-kW gas turbine with steam injection.[13] A 22·6% increase in useful power was obtained with a 3·56% addition of water.

TABLE I

Method	p_i	T_i	W_w/W_a	ΔU	$\Delta\eta$	ΔC
			Water Injection			
(*a*)	6·3	788	0·1	+40	−18	−24
(*b*)	—	—	—	+35	+10	—
(*c*)	—	—	0·05	+20	—	—
(*g*)	5·5	625	0·0356	+22·6	−7·5	—
			Steam Injection			
(*a*)	6·3	788	0·1	+38	+11	−14
(*d*)	5·05	760	0·2	+97	+36	−27
(*e*)	7·0	750	0·147	+58·2	+26·5	—
(*f*)	—	—	—	+50	+14·6	−25

For a comparative assessment, the main data for the methods (*a*) to (*g*) considered above are given in Table I, in which p_i = inlet pressure [kg/cm² abs.], T_i = inlet temperature [°C], W_w/W_a = ratio of weight of water to weight of air, ΔU = percentage variation of useful power, $\Delta\eta$ = percentage variation of efficiency, and ΔC = percentage variation of cost per kilowatt.

Detailed Analysis of Comparative Performance

The above data illustrate the possibilities of water injection in the combustion chamber of gas turbines. However, the information thus obtained is not always complete and mainly shows the effect of water or steam additions in plants subsequently modified for this purpose. For a full assessment, therefore, it is of interest to compare a conventional gas turbine with one specifically designed for water or steam injection, both turbines being considered primarily for peak-load power generation.

For operation with water or steam injection, it is assumed that the water available has a temperature of 15°C and that it is converted into steam at the same turbine inlet pressure and temperature as the combustion gases. Moreover, when a waste-heat boiler is included, as in Fig. 2, steam production (assuming saturated dry steam at the boiler exit) will be limited to values corres-

ponding to a temperature difference of not less than 30°C between the heating and the heated media. Finally, it is assumed that mechanical and electrical losses always have the same relative values, so that it is not necessary to include them in the comparison.

The comparison is limited to the simplest cases by considering that the gas turbine has no recuperator and no intercooler or intermediate combustion chamber, and that water or steam injection is obtained in accordance with the arrangements in Figs. 1 or 2. Further basic parameters are as follows :—

Range of pressure ratios considered ..	1 to 10
Air temperature at compressor inlet ..	15°C
Temperature of gases or steam and gas mixtures at turbine inlet	600, 700, 800°C
Polytropic efficiencies of compressor and turbine	0·85
Theoretical air/fuel ratio W_a/W_f for combustion	14·5:1

Fuel used :—Liquid hydrocarbon, with an h/c ratio of 0·16 (h and c being the respective weights of hydrogen and carbon in 1 kg of fuel) and a net calorific value (taking account of combustion-chamber efficiency) of 10,000 kcal/kg.

Since the cases considered are those in which the water or steam is injected after the compressor, so that only air flows through the latter, the calculations are simpler than for the case of injection into the compressor, as has been considered in a previous paper.[5]

For the conventional cycle without steam or water injection, it is necessary to make separate calculations for the three main components, i.e., the compressor, the combustion chamber, and the turbine, in order to determine (1) the power absorbed in compression, (2) the fuel consumption, and (3) the power developed in the expansion process. These values can be determined with a minimum of computation work by means of enthalpy/entropy diagrams published some years ago by the author.[14] These diagrams enable fuel consumption to be found directly; moreover, the diagram relating to turbine operation takes account of the composition of the gases, indicating its effect on enthalpy and on the isentropic exponent for the corresponding expansion process. It is known that the thermodynamic properties of combustion gases are practically independent of fuel composition, but vary with the ratio $r = W_1/W_2$, where W_1 = theoretical weight of air required for oxidation, and W_2 = weight of air effectively entering the combustion chamber.

Water or steam injection into the combustion chamber obviously has no influence on the work required for compressing 1 kg of air, but it affects both fuel consumption and the work produced during expansion. Fuel consumption is increased by the amount required to raise the water or saturated steam to the conditions prevailing at the turbine inlet. The work of expansion can be calculated by considering separately the steam and the combustion gases (modified by the additional fuel). The total work is the same as if the two constituents were expanded in separate turbines, of which the inlet and exhaust pressures would correspond to the partial pressures of the steam and the combustion gases. In fact, the changes due to partial pressures are to be considered only in the case of

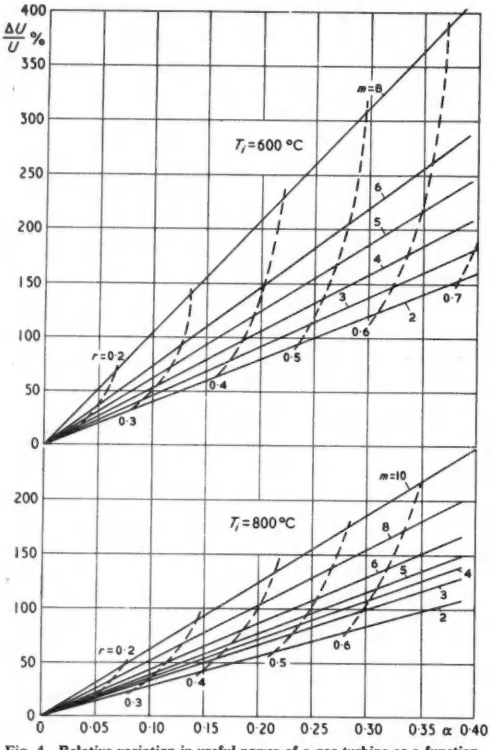

Fig. 4. Relative variation in useful power of a gas turbine as a function of the amount of water injected.

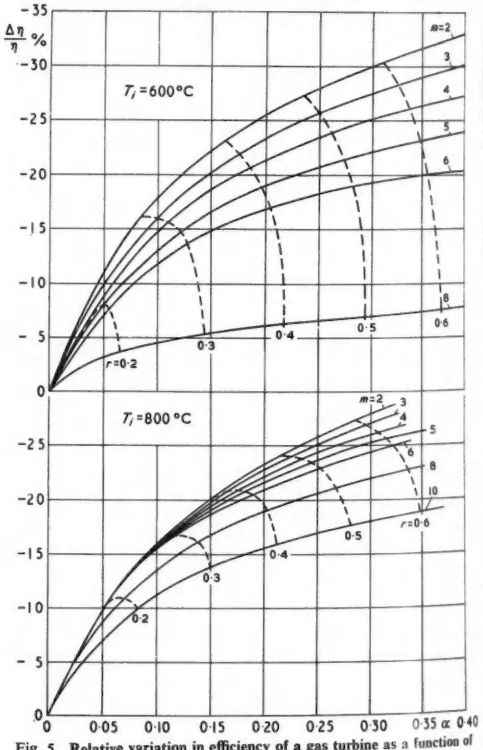

Fig. 5. Relative variation in efficiency of a gas turbine as a function of the amount of water injected.

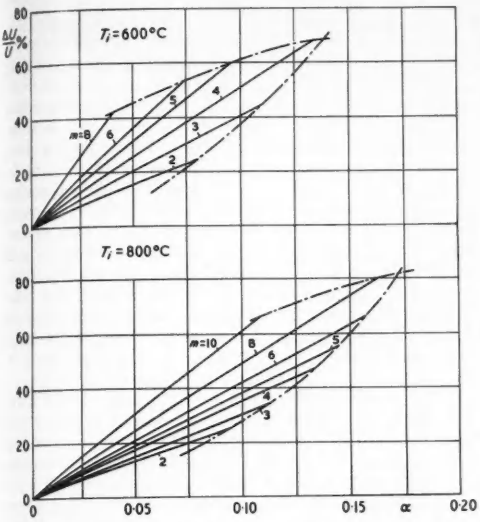

Fig. 6. **Relative variation in useful power of a gas turbine as a function of the amount of steam supplied by a waste-heat boiler.**

steam, since the thermodynamic properties of the combustion gases are practically independent of the pressure of these gases in the range of values investigated.

Results and Conclusions

The efficiency η [%] and useful work U [kcal/kg of aspirated air] of a simple gas-turbine cycle without water injection are given in Table II for various pressure ratios m and various turbine inlet temperatures T_i.

Table II

T_i		Pressure Ratio m 1·8	2	4	6	8	10
600°C	U	14	16	20·5	18·5	14·5	—
	η	10	11·5	18·5	20	—	—
700°C	U	16·5	19	27·5	28	25	—
	η	11	12	20	23·5	23·5	—
800°C	U	21	23·5	36·5	38	37	33·5
	η	11·5	12·5	21·5	25·5	27	27·5

The η-values do not include mechanical and electrical losses, etc. and are slightly higher than the actual values.

Consider a plant according to the arrangement in Fig. 1, operating with fixed values of pressure and temperature at the turbine inlet. The useful work per kilogram of aspirated air varies with the ratio $\alpha = W_w/W_a$ of the weight of water injected relative to the weight of air, with a practically linear relationship. The relative increase in useful work can be defined as

$$\Delta U/U = (U'-U)/U,$$

where U = work supplied by the conventional cycle and U' = work provided per kilogram of air by a cycle with water injection after the compressor. Values of $\Delta U/U$ for turbine inlet temperatures of 600° and 800°C are shown in Fig. 4, plotted against α. The graphs show that, for constant values of m, $\Delta U/U$ is effectively a straight-line function of α. Moreover, they show that α and $\Delta U/U$ can reach high values without assuming excessive values for $r = W_1/W_2$ (the ratio of theoretical to effective weight of air in the combustion chamber). Therefore, at least theoretically, complete combustion is possible, even when the flow of injected water is considerable.

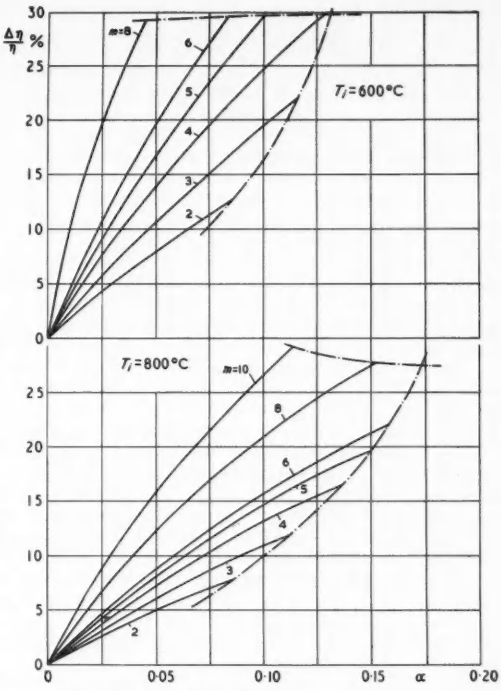

Fig. 7. **Relative variation in efficiency of a gas turbine as a function of the amount of steam supplied by a waste-heat boiler.**

A study of these graphs also shows that, with α constant, $\Delta U/U$ increases with increasing values of m but decreases with high values of T_i. It thus appears that water injection is particularly effective with moderate inlet temperatures. Furthermore, for a given value of α, an increase in $\Delta U/U$ (due to variations in m or T_i) is accompanied by a reduction in the air ratio r, i.e., excess air increases with increasing turbine output.

Similarly, Fig. 5 gives the relative variation in efficiency, i.e.,

$$\Delta\eta/\eta \quad = \quad (\eta'-\eta)/\eta$$

where η = efficiency of the conventional cycle and η′ = efficiency with water injection. It can be seen that $\Delta\eta/\eta$ is negative throughout the range of values considered. Its absolute value becomes greater with increasing values of α and decreasing values of m. The influence of pressure ratio m is particularly marked at moderate turbine inlet temperatures T_i. Calculation shows that $\Delta\eta/\eta$ even becomes positive, and increases with α, when T_i = 500°C and m = 10. This is because the efficiency of the steam cycle increases with pressure, whereas the efficiency of the cycle followed by the air and gases is unfavourably affected by increased pressure. The efficiency of the conventional turbine cycle with T_i = 600°C passes through a maximum for $m \cong 6$.

To sum up, it can be said that, both with regard to useful power and fuel consumption, water injection after the compressor is particularly attractive when the turbine is operated at a high inlet pressure and a moderate inlet temperature.

The next case to be considered is that of a cycle with steam injection, in accordance with the arrangement in Fig. 2. The corresponding curves for $\Delta U/U$ and $\Delta\eta/\eta$ as

functions of the steam/air ratio α are given in Figs. 6 and 7. For fixed values of T_i and m, the ratio $\Delta U/U$ is again linearly proportional to α but, in this case, the values of α and hence those of $\Delta U/U$ cannot exceed certain limits (shown chain-dotted). The upper limit occurs because the temperature difference between the heating and heated media in the waste-heat boiler is not allowed to be less than a specified minimum value (30°C in these graphs). The lower limit exists because the temperature of the exhaust gases at the exit of the waste-heat boiler must be higher than the dew point. Its value depends, of course, on the composition of the combustion gases (and hence on the type of fuel used), as well as on excess air and the quantity of steam injected. For simplicity, the final temperature of the combustion gases has been assumed to have a fixed value of 120°C in all cases, and this condition determines the second chain-dotted line in Fig. 6. Within these two limits, the conclusion arrived at in this case is the opposite to that which was reached previously, i.e., the ratio $\Delta U/U$ reaches its maximum for moderate values of m ; moreover, this maximum is lower for $T_i = 600$°C than for 800°C. Obviously, the same limits also appear in the graphs of the $\Delta\eta/\eta$ curves (Fig. 7). In contrast with Fig. 5, the values of $\Delta\eta/\eta$ in this case are always positive.

Together with the values for conventional cycles given in Table II, the above graphs make it possible to assess the influence of water or steam injection on the useful power and efficiency of an installation. Moreover, the data from previous literature provide some indications of the effect of this addition on capital costs. It would be desirable if manufacturers could subject this question of costs to a further analysis, with detailed estimates for each particular case, so as to indicate the optimum solution. It was partly with a view to facilitating such a study that the above comparisons were based on the same turbine inlet pressures and temperatures for plants with and without water or steam injection. The effect of injection would probably be even more favourable if the optimum operating conditions were selected for each of the solutions considered. These optimum values can also be derived from Figs. 4 to 7, since they provide all the necessary data for determining the work U' and the efficiency η' for any values of T_i, m, and α, with either water or steam injection.

Another important factor to be considered is the behaviour of the combustion chamber and turbine with a flow of combustion gases and steam. It was previously mentioned that it has been proposed that the peak-load operation with water or steam injection should have a duration not exceeding 1000 hr per year.[6] This limitation is attributed to the fact that water injection increases the temperature at the turbine exhaust and may therefore reduce the service life of the turbine rotor.[8] However, this reason does not seem to be the only one since, if a gas turbine were designed from the outset for continuous operation with water or steam injection, it should be possible to make its rotor capable of withstanding the corresponding final temperature under continuous running conditions. In the same paper,[8] it is noted that, in order to avoid deposits in the turbine, the water should be treated to reduce its solid content to a value not exceeding 1 milligram per litre. Whatever may be the reasons for the 1000-hr limitation, it has no practical effect on the industrial utilization of a peak-load power plant, since peak-load requirements are usually less than 1000 hr per year. Moreover, the tests carried out by Brown Boveri[15] show that water injection has not led to an increase in the deposits formed by the unburned constituents of heavy fuels.

Further problems occur with regard to operating requirements. It is evidently necessary that the plant be able to start without water or steam, the injection taking place only when a certain fuel flow has been reached. Under such conditions, the compressor will be subjected to variations in operating conditions which may result in surge, though this difficulty does not appear to be very great, since the means for avoiding surge are now fairly well known. Moreover, variations in operating conditions can be reduced by allowing expansion of the gas to take place in two turbines connected in series, the first of these being coupled to the compressor, while the second is connected to the generator, both turbines being enclosed in the same casing. This solution, which has been adopted by several manufacturers, has the advantage of permitting variation of the rotary speed of the compressor, the low-pressure turbine alone being required to rotate at constant speed.

Another limitation may arise as a result of difficulty in obtaining good combustion in the presence of an appreciable quantity of steam or water. The method adopted by Brown Boveri is to inject the water directly into the combustion chamber, i.e., into the section where temperature and turbulence are particularly high.[15] This combustion chamber does not seem to have been specially designed, so that the encouraging results already obtained by this manufacturer could no doubt be still further improved.

In conclusion, it can be stated that the theoretical and experimental work on gas turbines with water or steam injection confirms, even in its present stage, the interesting possibilities of this process for peak-load energy production. The study of a machine specially designed for this purpose should therefore lead to even more favourable results and could thus contribute to reducing the cost of peak-load energy.

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Non-Destructive Testing of Metals with Eddy-Currents

By R. HOCHSCHILD. (From *Control Engineering*, Vol. 4, No. 8, August 1957, pp. 79–85, 12 illustrations.)

MUCH development work is at present directed towards applying complete non-destructive inspection to materials on the production line. Several types of instrumentation, including radiation, ultrasonic, magnetic, and electrical devices, lend themselves to such " on-the-fly " inspection. One method of special interest is eddy-current testing, by virtue of its being fast, easily compatible with electronic control circuits, and suitable for checking several materials characteristics, in addition to seeking out mechanical flaws. Minute eddy currents induced by a radio-frequency field explore the material or part and can be made to yield information on dimensions or on the presence of flaws or faulty mechanical, metallurgical, and chemical properties. By means of suitable controls linked to the eddy-current instrumentation, defective materials or parts can be rejected, sorted, or labelled. Equally important, in view of to-day's high interest in feedback gauging and inspection, is the adaptability of eddy-current equipment to continuous adjustment of the production process through a feedback-control loop.

The magnitude of eddy currents and the paths they follow within a particular piece of metal are affected by the resistivity of the metal and by discontinuities and boundaries, such as cracks, holes, laps, seams, and porous areas. The detection of such defects in metal objects of relatively uniform shape has been one of the principal fields of application of eddy-current testing. Here, eddy-current testing has often replaced the older methods of visual powder-particle, penetrant, and radiographic inspection.

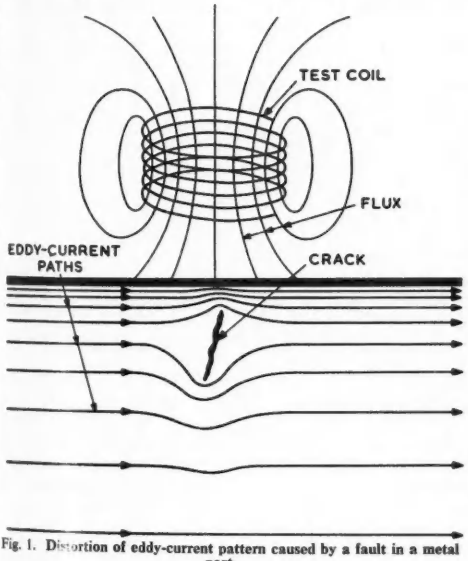

Fig. 1. Distortion of eddy-current pattern caused by a fault in a metal part.

Eddy currents have many of the properties of a compressible fluid. They flow in certain patterns and distributions determined, first, by the design of the test coils which set up the radio-frequency waves and, second, by the frequency of oscillation of the waves. The frequency, in particular, controls the depth to which eddy currents penetrate the surface. Currents encountering an obstacle, such as a crack, are diverted around it, being compressed and weakened in the process, as illustrated in Fig. 1. The current induced by the applied RF energy, in turn, sets up its own magnetic field. The resultant field external to the part contains information on the position, shape, and size of any discontinuity distorting the currents and may be analysed electronically to yield this information in useful form.

A further factor influencing eddy currents in a given part is related to its dimensions. This has led to the availability of sensitive equipment for the determination and control of the dimensions of manufactured products such as rods, tubing, bolts, pistons, and ball bearings ; the thickness of sheet, plate, strip, or foil of one metal plated or coated on another ; and the thickness of insulating coatings on metal surfaces. Measurements accurate to better than one millionth of an inch can be made from one side only and without contacting the part. With equal facility, tests can be conducted either during production of a part to monitor the forming process, or after the part has been placed in operation. An application of in-use testing is the detection of corrosion in tubing, oil-well casings, and the like.

Equipment Characteristics

Like X-rays, eddy currents leave no after-effect in metals. The entire production, not just a statistical sampling, may therefore be tested—an important advantage where the quality of parts must be guaranteed.

Eddy-current testing lends itself to production-line use because the operations involved are generally simple and fast. The parts to be tested may be passed by some type of motor drive, conveyor feed, or by hand through or under the test coils which send and receive the radio-frequency signals. The return signals are studied for faulty conditions by electronic circuits having a built-in memory of what to accept and what to reject. The response of the test instrument can be translated into an oscilloscope pattern, a tape-chart recording, the flash of a reject light, the action of a relay which automatically expels the faulty part or paints the faulty spot, or an electronic impulse which controls parameters.

Where parts are too large or where they are already in assembled form and cannot be brought to the equipment, eddy-current tests can be made with portable instruments. Such an instrument, transistorized and battery-operated, may measure 4 × 4 × 6 in. and weigh only 3 lb. It may be suitable for identifying alloys and heat-treatment conditions and for making quick checks of strength, hardness, or degree of carburization. Coloured lights and a meter provide identification or indicate various degrees of faulty conditions.

Most eddy-current equipment operates in the long-wave range below the standard broadcast band and including the audio frequencies. In the testing of non-ferromagnetic metals, frequencies between 1 and 500 kc, depending on application, are common. Ferrous metals are generally tested at still lower frequencies.

Theory of Operation

Although the mathematics of eddy-current testing tend to be cumbersome, the qualitative aspects of the theory are not difficult to grasp. Fig. 2 is a schematic

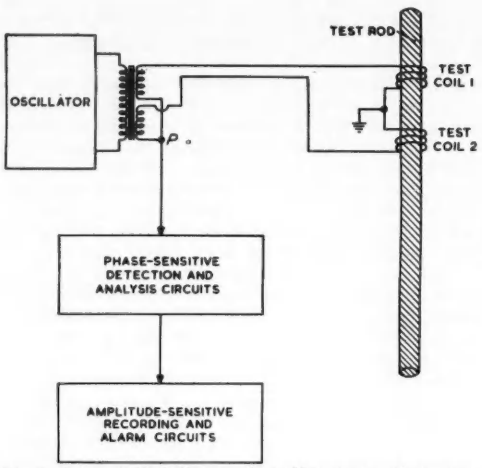

Fig. 2. Schematic block diagram of an eddy-current test instrument.

block diagram of an instrument used for flaw detection in tubing and bars. Coils 1 and 2, about $\frac{1}{8}$ in. apart, surround the testpiece (a rod in this case) and carry an alternating current of frequency f. The electromagnetic field established by each coil sets up eddy currents in the rod. Under appropriate boundary conditions, the phase, direction, and amplitude of the eddy current at any point in the rod can be computed from appropriate formulae, provided the conductivity σ, permeability μ, and radius a of the rod are known. The currents follow circular loops concentric with the rod and in a plane perpendicular to the rod axis, and tend to be largest near the surface, dying out towards the centre because of skin effect.

Fig. 3 shows plots of the amplitude j of eddy currents induced in a rod versus the ratio of r (radial distance from centre) to a (radius of the rod). Each curve in the group relates to a different set of values of the test parameters. These values are lumped in a constant K, defined by the equation:

$$K = 2\pi\ \sigma\ \mu\ a^2\ f$$

The constant is similarly defined for the family of curves in Fig. 4, representing the relationships between the phase angle φ of the eddy currents and the ratio r/a. The results are perfectly general among rods and apply to any σ or μ (i.e., any metal), any rod radius a, and any test frequency f. In fact, by selection of appropriate test frequencies, the measurements taken for a rod of any material can be made to follow the curves of Figs. 3 and 4 for any value of K. The second column of the accompanying table shows the test frequencies needed to achieve this correspondence for 1-in. dia. rods of aluminium ($\sigma = 3{\cdot}54 \times 10^7$ mhos/metre and $\mu = 4\pi \times 10^{-7}$ henry/metre). The table also includes for non-magnetic 18-8 stainless steel frequencies which, as will be noted, are 25 times higher than those for aluminium. This is because the conductivity of stainless steel is only 4% that of aluminium. The frequencies recommended for most other common metals lie between the extremes presented in this table.

TYPICAL TEST FREQUENCIES

K	Aluminium	Stainless steel
4	89 cps	2255 cps
9	199	5040
16	354	8950
49	1088	27,500
100	2210	56,000
625	13,900	352,000

From Figs. 3 and 4 three important facts can be deduced. First, skin effect becomes more pronounced with increasing K or f. Thus, higher test frequencies ($K = 100$ or more) are used to inspect surface regions, while lower frequencies deepen penetration into the part at the cost of sensitivity to surface defects. Second, at any given frequency the magnitude of j falls off with increasing depth, as does test sensitivity. Hence, eddy-current inspection is more suited to surface and near-surface zones than to interiors. Third, the lagging phase angle of the current increases with depth, thus providing a basis for measuring the depth of a flaw. In addition, the phase-angle behaviour makes it possible to determine whether an indicated defect is actually a flaw, or a conductivity or diameter change.

The sole measurement made by the equipment is of voltage V at point P (Fig. 2). With no rod within the coils, this voltage is zero because, in the bridge circuit shown, there is no difference in the effective impedances of coils 1 and 2. When a rod enters coil 1 only, a voltage V_1 appears at P because the eddy currents induced in the rod weaken the field of coil 1 but have no effect on coil 2. The amplitude and phase of V_1 may be plotted as a vector

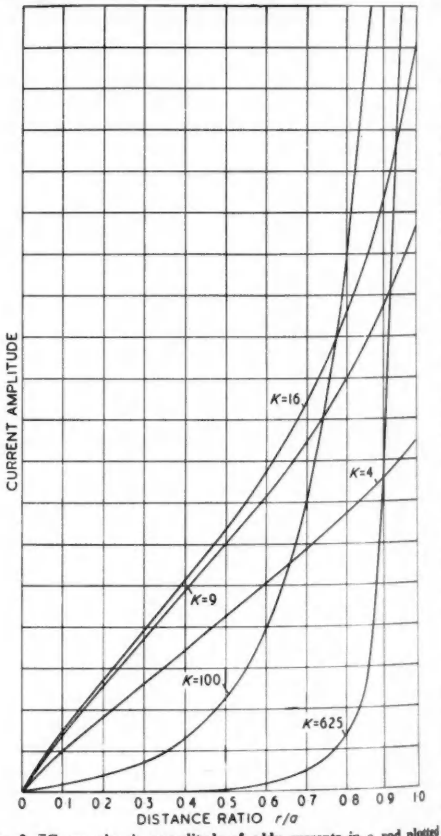

Fig. 3. Curves showing amplitude of eddy currents in a rod plotted against radial distance from centre for various values of K.

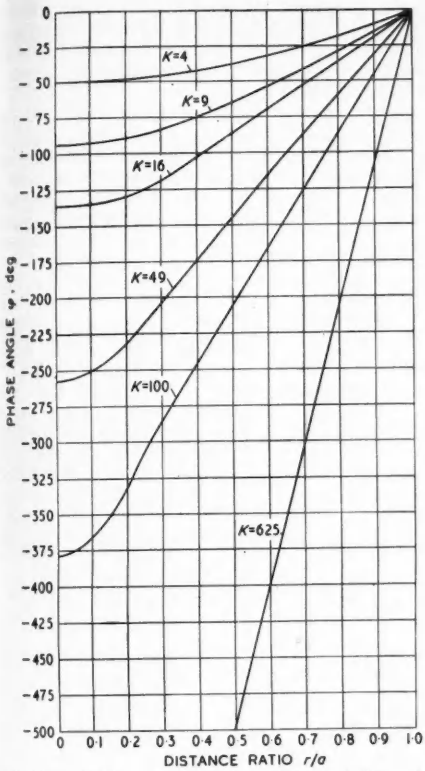

Fig. 4. Phase of eddy currents plotted as a function of distance from centre for various values of K.

on a two-dimensional graph (Fig. 5). Amplitude is the distance V_1 from the origin, and phase is the counter-clockwise angle φ measured from the horizontal axis.

When the rod extends through both coils, their impedances will again be equal, provided the portions of the rod in each coil are in every way identical. Under these conditions, V drops back to zero and the instrument shows no response.

As the rod moves on during the test, a flaw may be introduced into coil 1. The flaw obstructs the normal pattern of eddy currents, modifying the field threading coil 1 and thereby causing an unbalance voltage V_2 of certain amplitude and phase to appear at P. As drawn in Fig. 5, the vector V_2 represents a narrow surface crack. Theory and experience have shown that flaws of other shapes and positions, diameter changes, or resistivity changes affect V differently, affording a means by which the cause may be identified. For example, V_3 represents a narrow interior crack, V_4 a wide surface tool mark, V_5 a diameter variation, and V_6 a purely resistive variation associated, say, with inadequate heat treatment at that point.

By designing the equipment with channels which are sensitive only to signals of certain phases, the instruments can be made to react to particular types of flaws (e.g., cracks) and ignore other types of flaws (e.g., tool marks or diameter, permeability, and resistance variations). An application of this means of selective testing is the inspection of non-magnetic stainless-steel tubing. The latter often contains internal fabrication stresses which modify the slight permeability of the tubing and cause irregular test signals far greater than those due to small flaws. Phase selectivity allows almost full occlusion of the stress signals.

After singling out and amplifying the desired flaw voltages, the phase-sensitive analysis circuits transfer these signals to alarm circuits and to devices producing chart records. The alarms consist of coloured lights and a mechanical device to paint the defective spot and are not activated until the signal exceeds a certain preset amplitude. Thus, flaws below a certain size may be allowed to pass, if considered harmless. In the testing of small parts, the alarm circuit may consist of a mechanical switch which automatically diverts faulty units into a reject bin, or a set of such switches for sorting parts, say, to degree of hardness.

Applications

Eddy-current equipment cannot in general provide absolute measurements of properties such as hardness, strength, chemical and alloy composition, decarburization, internal stresses, ageing, and work hardening. In non-ferrous metals, only resistivity can be quantitatively measured. Hence, any information on other metal properties which can be derived from an eddy-current test must be based on the effect of changes in these properties on the resistivity of the part. In ferrous metals, however, permeability, coercivity, and other magnetic properties are capable of absolute measurement.

Chemical Analysis:—Eddy currents are composed of free electrons caused to drift through a metal under the influence of an induced electromagnetic field. The metal atoms are arranged in an orderly—or almost orderly—lattice structure. In their travel, some electrons collide with the atoms of the metal lattice or with impurity atoms present and are scattered. These electrons lose part of their energy to the lattice atoms, and this energy is then dissipated in the form of heat. It can be shown that a perfectly orderly lattice cannot scatter electrons, and hence has zero resistivity. In fact, metals are resistive, because they contain deviations from the perfect lattice.

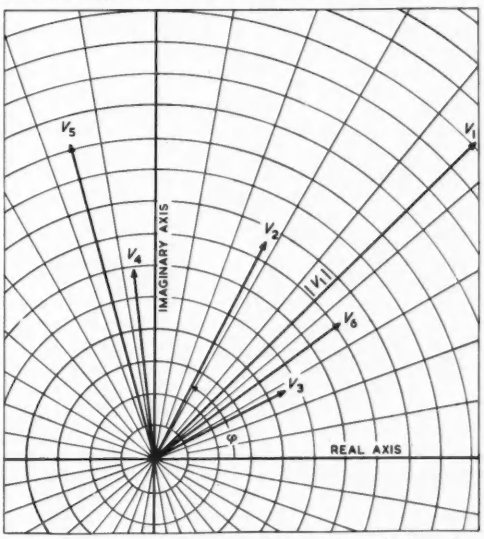

Fig. 5. Two-dimensional plot of amplitude and phase of bridge voltage accompanying various types of flaws and conditions.

The deviations are caused by thermal motion of the atoms and by imperfections such as dislocations and impurity atoms. That portion of the resistivity which is not due to thermal vibrations in the lattice, i.e., the portion which does not vanish as the temperature approaches absolute zero, is called the residual resistivity.

Impurity atoms in a metal tend to distribute themselves randomly in the lattice and out of line with the neat rows of metal atoms. Such atoms destroy the order of the lattice and act as scattering centres for electrons. Impurity content causes residual resistivity, which is proportional to the cross-section of a given kind of impurity atom multiplied by the number of impurity atoms present per unit volume. Various impurities may have widely different effects. For example, 100 ppm of phosphorus increases the resistivity of copper by about 10%; 100 ppm of iron in copper raises this factor by about 2%. While even very small quantities of impurities are detectable by eddy-current testing, it is not generally possible to determine actual concentrations if there are several impurities with different cross-sections. However, the method does serve to test the overall purity of high-purity metals and to indicate deviations from specified concentrations of impurities in other than high-purity metals.

The chemical composition of process streams is sometimes controllable by eddy-current analysis because this method does not require high conductivities. For example, a change in the concentration of nitric acid in a process stream changes its resistivity; consequently, stream content may be regulated by surrounding a special non-conducting section of the process tubing with a test coil and controlling the feed of nitric acid through a feedback loop.

Alloy and Heat-Treatment Identification:—From the electrical point of view, an alloy may be thought of as a metal with high impurity content. The analysis is complicated, however, in that the alloying atoms are rarely uniformly distributed, except after a "homogenizing" heat treatment to promote solid diffusion. More often, an opposite type of heat treatment, involving precipitation (or ageing) of certain combinations of alloying elements into extremely minute particles between crystals of the metal, is used to increase strength. Precipitation collects electron-scattering centres into islands along crystal boundaries, leaving fewer scattering centres in solution. Scattering and hence residual resistivity generally change on precipitation. Since it depends on the number, composition, and size of the precipitated particles, the amount of scattering is determined by the choice of both alloy and heat treatment. It also depends in a smaller way on subsequent cold work, which increases scattering centres.

The identification of alloys is not as hopelessly complicated as it seems, however, because certain composition and heat-treatment standards have been adopted by the industry. Thus, identification of many common alloys and of their heat-treated condition is possible.

Strength and Hardness:—The effects of heat treatments, such as precipitation, used to achieve strength and hardness in alloys account for the relationship between these properties and resistivity. The misfit of precipitated particles in the lattice causes internal stresses which offer resistance to the passage of dislocations, thereby hindering slip and increasing strength. They also offer resistance to the passage of electrons. Resistivity generally (but not always) increases as hardness and strength increase.

Cold work raises both strength and resistivity because the new dislocations produced serve to hinder further slip and scatter electrons. However, the effect on resistivity is comparatively small, e.g., about 2% in heavily cold-worked copper.

Carburization:—Ferrous parts, such as rolled steel rod, may be carburized to a greater or lesser degree for extra surface hardness. The amount of carburization and the presence of decarburized areas are conducive to measurement by eddy-current testing under controlled conditions. The carbon atoms constitute an impurity and radically alter both the electrical and magnetic properties of steel.

Conclusion

Eddy-current testing may be described as a more powerful method than has hitherto been available for the industrial control of many aspects of metal quality. Its greatest difficulties arise from its being sensitive to too much rather than to too little. For this reason, it is important to design individual units of equipment so that they are sensitive only to a limited number of conditions. Such designed-in selectivity may be achieved through phase-sensitive circuits, special choice of test frequency, and special test-coil design.

Design and Applications of "Solion" Electrochemical Transducers

(*Concluded from page 432*)

changes in three dimensions. Any change in direction of movement causes a measurable change in current output, which, in turn, activates the appropriate control devices.

Thermostatic Controls:—

An electrochemical unit has been developed to control furnace and room temperatures. The instrument detects the rate at which a given temperature change is taking place, rather than sensing that the change has already occurred. Any tendency to overshoot or undershoot the desired temperature range is eliminated, and the instrument can be made sensitive enough to respond to the heat of the human body, to practically any source of light in its vicinity, or to mild pressures.

Sound-Sensitive Meters :—

A sound-exposure meter for measuring the cumulative exposure of personnel to jet-engine noise is also being developed. In this application, the fluid in the electrochemical unit becomes progressively darker on exposure to high-intensity sound, providing a warning to personnel carrying the meter when a given colour indicates exposure to a predetermined amount of sound.

Conclusion

The basic theory and technology of solion units are now fairly well understood. One large area of application is in the design of hydraulic-electrical circuits complementary to those of semiconductor devices. Although, in certain low-frequency and integrator applications, solions are superior to transistors and electronic tubes, they cannot at present be used in place of such devices in many circuit applications, particularly in the medium- and high-frequency ranges. At the moment, the main function of solions is to produce electrical from non-electrical stimuli.

5th EUROPEAN MACHINE TOOL EXHIBITION

Held at Hanover between September 15 and 24, the 5th European Machine Tool Exhibition was the largest in the series, demands for space exceeding by about 25% the previous record established by the 4th Exhibition at Milan in 1954. Over 1000 constructors of machine tools and equipment participated, of which about 5% were British firms, and the stands covered an area of about 600,000 sq ft, in eleven main halls, one of which was devoted to the display of precision tools, testing machines, and measuring equipment, representing the products of nearly 250 manufacturers. In our September issue, we gave a preview of some items shown at this Exhibition. In the following pages, a further selection is included.

Exhibits by **Maschinenfabrik Deutschland A.G.,** of Dortmund, Germany, included the headstock and faceplate of a heavy combined facing and centre lathe. This machine (Fig. 31) is of movable unit construction, consisting of the headstock unit, stand carriage, toolpost saddle on an independent bed, and a tailstock unit. These units can be arranged on a baseplate in any required position.

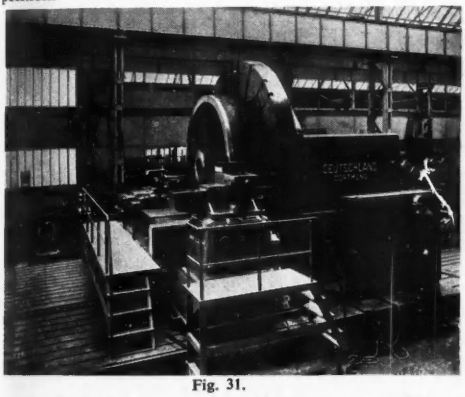

Fig. 31.

The feed to the toolpost saddle is transmitted by a special arrangement, referred to as an " electric shaft ", consisting of a motor coupled to the main spindle of the headstock and a feed motor at the saddle bed. The rotors of both motors are coupled electrically to ensure synchronous running. Changes in direction of feed are accomplished through electrical clutches, which can be used to copy on full turning length by means of electrical tracer control. A threading attachment is available as an extra, and threads can be cut on full turning length. Longitudinal travel of the toolpost is effected via a separate leadscrew and nut, the drive being taken from the existing electric shaft.

This lathe is designed to take workpieces up to 60 tons weight between centres, and 16 tons freely suspended at the faceplate. The faceplate diameter is 158 in., the centre height 87 in., and the maximum distance between centres 158 in. This last dimension can, of course, be increased, if extra baseplate length is added. The movable stand carriage or short traverse toolpost unit is provided so that the facing lathe can be used in a more universal manner.

The Nassovia LRS. 10/9 " Transfer-Rotor " demonstrated by **Nassovia Hanns Fickert G.m.b.H.,** of Langen, Germany, is a 10-station rotary-table chucking automatic. This machine incorporates nine vertically operating spindles spaced round a circular horizontal table. The table remains stationary, and the chuck carrier in the centre of the table is indexed so that each workpiece is held over each spindle in turn. Each chuck is also capable of being indexed on its own horizontal axis, thus enabling different faces of the workpiece to be presented to the operating spindles. An advantage of the machine is the small amount of floor space it occupies, the diameter of the machine being only just over 5 ft. The maximum size of components accommodated is about 5 × 5 × 5 in.

Other Nassovia exhibits included their V.11 die-sinking machine, which is a hand-controlled type equally suitable for the production of dies or moulds. Feed motion, i.e., longitudinal and cross movement of the tracer and cutter, is effected hydraulically. Manual control is by lever at the front of the machine, and by means of this control feed is started or stopped, and its direction and value determined. The position of the control lever always indicates the direction of feed. Cutting pressure is regulated by a handwheel, and a pressure gauge indicates the amount, so that continuous supervision by the operator can be maintained. Two tables are provided for setting the master and the workpiece, and these are adjustable independently of each other. The V.11 machine is capable of copy-milling the upper and lower halves of a die, provided that these are symmetrical, from the same master. The maximum height of 29½ in. between table and spindle nose ensures that deep die blocks can be accommodated.

The Nassovia VA.1.11–2 die-sinking machine shown is a fully automatic machine universally adjustable for parallel-stroke milling and contour milling. An automatic limiting device controls the length of milling strokes. This die sinker is equipped with two milling spindles and one tracer head. The table for the VA.1.11–2/2000 machine (Fig. 32) was also exhibited. The effective range of copy milling covers about 79 × 15¾ in. when the machine is used with one spindle in operation. When two spindles are used, it is capable of covering two working ranges of 31½ × 15¾ in. each simultaneously.

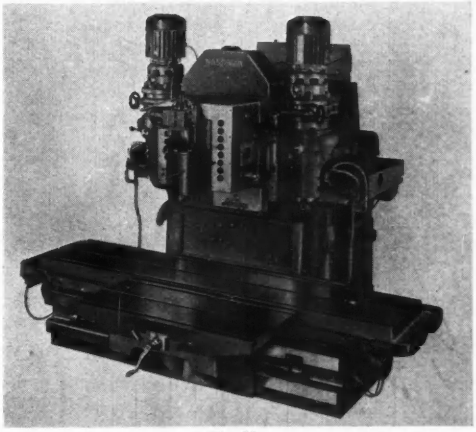

Fig. 32.

A complete range of cold sawing machines, segmental saw blades, and saw-blade sharpening machines was exhibited by **J. F. Ohler,** of Remscheid, Germany. An Ohler automatic hydraulic cold circular sawing machine is illustrated in Fig. 33. These cold saws are so designed

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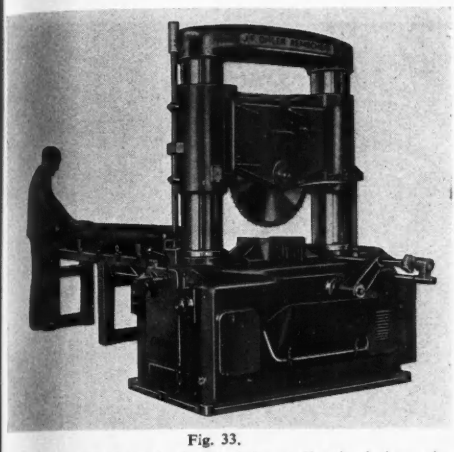

Fig. 33.

that the workpiece is located immediately below the centre of the saw, ensuring the shortest cutting traverse and the minimum cutting time. The material to be sawn rests on a roller-type conveyor track, and the rollers are driven by an oil motor via chains. When hand operation is required, the bar stock is fed by the roller drive up to a stop-bar fitted at the front of the machine. This bar is swung out of position when automatic feed is employed. The automatic feed mechanism operates a pair of adjustable tongs which grip the bar and feed it forwards to a predetermined length at each automatic cycle. The material is automatically clamped on either side of the saw blade in a hydraulic duplex vice.

In addition to examples from their range of duplicating and turret lathes, **Maxnovo,** of Novara, Italy, exhibited their "Telephotomation" automatic punched-card system for the automatic control of machine tools. The system, which is simple, practical, reliable, and comparatively inexpensive, can be applied to many types of machine tools, provided that their movements are servo-controlled.

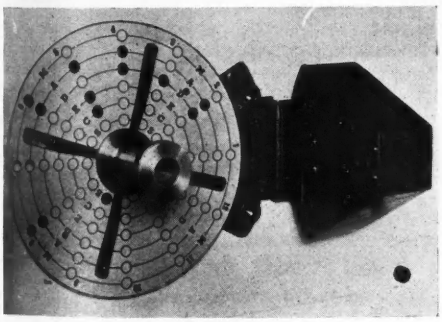

Fig. 34.

Only one impulse is necessary to operate the system, which is of the analogue type and is divided into two sections, i.e., motion or functions, and time or length. A selector device using interchangeable punched cards selects the functions or movements required at a certain time. Each movement or function is controlled by a photoelectric cell through a magnetic amplifier and a binary system. A view of this punched-card unit for a six-movement machine, with the corresponding photoelectric-cell unit (shown open) is illustrated in Fig. 34.

The step selector punched-card unit is controlled by impulses obtained through a time dial, which may be connected to the machine in different ways, depending on the type of machine tool to be controlled. At the end of the cycle, the punched-card unit returns to its zero position and is then ready for the next cycle.

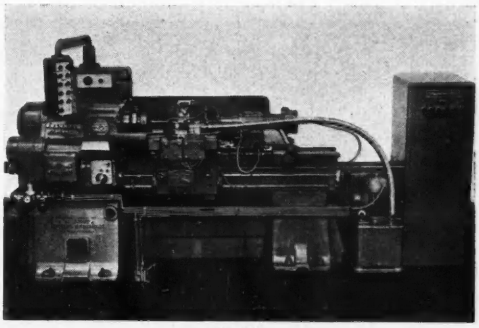

Fig. 35.

Fig. 35 shows a Maxnovo model A2-S duplicating lathe for gun barrels, with two duplicating slides and a dual template for roughing and finishing cuts, and equipped with the "Telephotomation" control unit, shown at the right of the illustration. Signal lamps and illuminated numbers at the top of the control cabinet indicate the sequence of the cycle. The punched-card unit is housed in a compartment below, and the time dial in another compartment underneath.

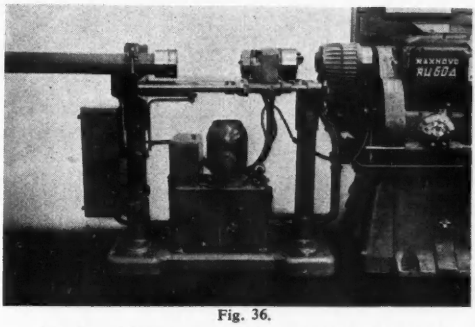

Fig. 36.

Another Maxnovo exhibit was their "Bar-Max" automatic bar feed unit, which provides a positive automatic feed for drawn or rolled bars and which is intended for application as a self-contained unit to different types of lathes. The bar feed is completely automatic and is performed with the spindle rotating. The cycle is initiated by operation of a push-button and includes opening of the spindle collet or chuck, feeding of the bar over a predetermined length, positive stop of the feed, closing of the spindle collet, opening of the feed chuck, and return of the feed slide against an adjustable positive length-stop. Fig. 36 shows the "Bar-Max" unit applied to a Maxnovo RU-60A turret lathe.

Exhibits from **British Timken Limited** covered a comprehensive range of taper roller bearings for machine-tool applications, with particular emphasis on those for work and cutter spindles, including grinding spindles.

Indicative of the improvements which have been effected in bearing design, manufacture, and application, British Timken featured their high-speed spindle mounting for obtaining higher speeds with sustained accuracy. When a spindle is operated at high speed, it expands radially, as well as axially. This radial expansion takes place a little before the axial expansion, and the bearing tends to tighten. If the bearing adjustment has been set closely initially, then excessive preload can develop. This occurs between the time of starting the machine and the time it takes to get up to operating

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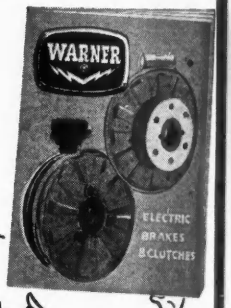

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temperature. It is in order to overcome this that the high-speed mounting adaptor has been developed. The front bearing and the cone of the rear bearing are mounted in the usual manner. The rear bearing cup is mounted in the adaptor, and the land directly above the cup is made smaller in diameter than the bore of the headstock. The other end of the adaptor is larger and is a press-fit in the headstock. In operation, the rear bearing and adaptor expand radially into the clearance between the headstock bore and the adaptor. In this way, both front and rear bearings are relieved of any additional preload. With this stabilizing device it is possible to run spindles at very much higher speeds than were previously practicable.

Among a comprehensive selection of gear-cutting and gear-testing equipment exhibited by **W. Ferd. Klingelnberg Söhne,** of Remscheid-Berghausen, Germany, the range of Klingelnberg hobbing machines for the production of large spiral bevel gears (" Palloid " gears) was represented by the model AFK153 machine shown in Fig. 37. This machine is primarily intended for crown-

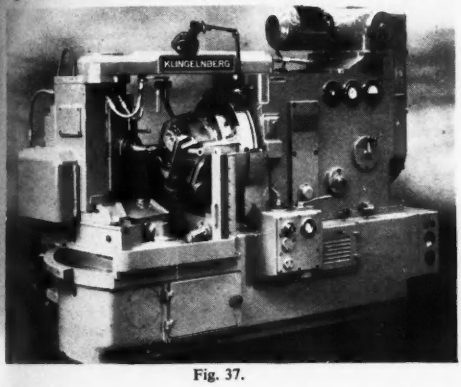

Fig. 37.

wheels, and can accommodate work up to 14½ in. in diameter and 6 D.P. Featuring simple setting arrangements, the AFK153 is equally suitable for jobbing or long-run work. Furthermore, it may be obtained in a model suitable for hobbing small quantities of crown-wheels and pinions, or for large batches of pinions to be machined in only one cut. Gears with slight or pronounced spheroidal tooth form can be produced to suit individual requirements merely by amending the basic setting with the aid of slip-gauges, but without the need to use a hob other than of standard form. The machine structure is entirely rigid, with sturdy bearings and spindles to absorb vibration, even at high rates of stock removal.

The latest model of Klingelnberg worm grinding machine is the HSS33B, shown in Fig. 38, one of the principal improvements being the introduction of a newly developed form-dressing attachment. This device transmits the profile of a single-sided template to a 19-in. diameter double-taper grinding wheel through the simultaneous action of two diamonds. Both flanks of a worm thread can be ground simultaneously on the forward and reverse strokes, or one flank can be ground on the forward stroke and the other on the return stroke. Alternatively, one flank can be ground on both forward and return strokes. Where there is a change from one flank to the other, a backlash eliminator ensures accurate location. Each forward and backward movement of a lever initiates a hydraulically operated stroke of the diamonds dressing the sides and periphery of the grinding wheel, compensation for reduced wheel diameter being automatic. An additional generator-type dresser and a template-grinding attachment are supplied for producing templates for " control worms " up to 7⅞ in. diameter, whose flanks are formed by the spiral of a straight generator.

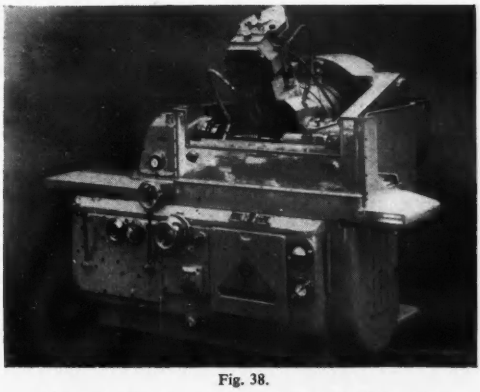

Fig. 38.

Of gear-testing equipment exhibited by Klingelnberg, their model PZ375 universal gear tester (Fig. 39) is of special interest. Available with an extremely wide range of accessories, this equipment can be used for two-flank rolling tests on spur and bevel gears and worms, as well as for the majority of individual error tests, such as indexing, pitch and gear concentricity tests, and inspection of worm and gear-cutting tools. Involute and helix tests, and rack and internal gear testing may also be carried out.

Fig. 39.

Of particular value is the steplessly variable motor-driven rotation of the gears during the two-flank rolling test, in addition to the steplessly variable test load by pendulum scales in the base of the machine, and the recording of the results on chart paper, with speeds variable from 0·08 to ⅝ ips. The mechanical recorder normally has steplessly variable magnification from zero to 250:1, although a top limit of 500:1 can also be supplied.

Exhibits from **Misal s.a.s. Leto,** of Milan, included a comprehensive range of lathes, tool and cutter grinders, horizontal and vertical milling machines, slotting machines, shaping machines, and universal grinding machines. Of these, the " Mercur K 16 " high-precision medium-duty lathe (Fig. 40) is of special interest, owing to the incorporation of two completely independent gearboxes, one for thread-cutting operations, and the other for turning operations, with feeds ranging from 0·002 to 0·048 in., all of which can be selected without stopping the machine. This lathe has eight spindle speeds, and accommodates a height of 8 in. between centres, a maximum swing over

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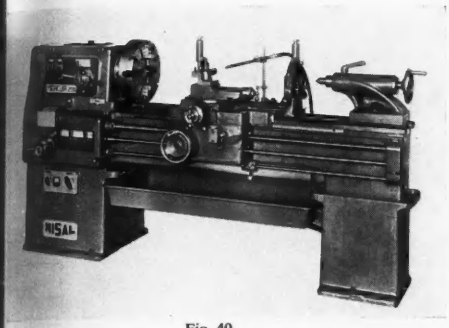

Fig. 40.

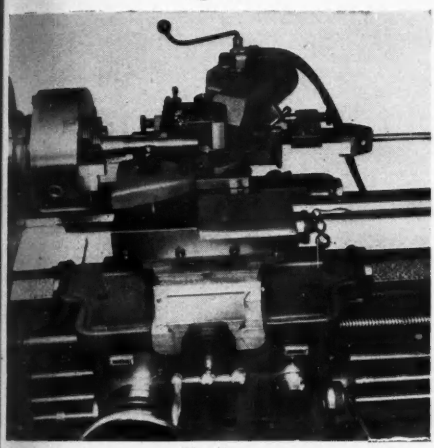

Fig. 41.

the bed of 16½ in., and a distance between centres of 40 in. Other lathes exhibited included the "Ticino K 13" light-duty lathe, the "Meteor K 15" universal medium-size precision lathe, the "Heron K 18/A" high-precision medium-duty lathe, the "Marathon K 24" heavy-duty lathe, and the "Olona TR.25/P" high-capacity production turret lathe. Also shown was the "Copy-Matic" hydraulic copying attachment (Fig. 41), which can be fitted at the rear of any make of centre-lathe and which can produce template profiles of any type with angles up to 90 deg. A special turret with a quick-change toolpost permits turning and facing work, without changing settings.

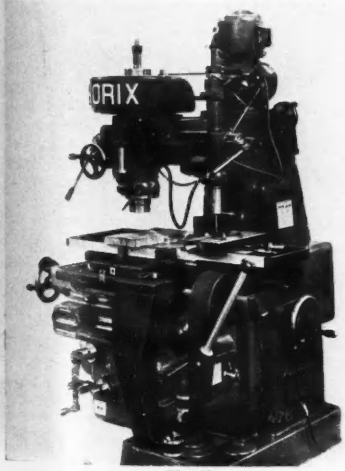

Fig. 42.

Tool and cutter grinders exhibited by Misal were represented by the "Horn 500" universal machine, which accommodates a maximum diameter of 9 in. and a distance between centres of 19¾ in., while milling machines included examples from the range of "Cervinia" high-precision universal or horizontal units, and the "Horix Duplomill" high-speed vertical milling machine (Fig. 42), which is equipped with the "Duplomill" mechanical duplicating attachment and is designed for high-precision work on dies which are difficult to machine with standard milling equipment.

Shaping machines from Misal included a range of "Ariston" models, and also their "Aristomatic", which is a gear-driven shaping machine with universal table and rapid power traverses. Slotting machines and universal grinding machines were represented respectively by the "Gardone GVT/200", a vertical gear-driven precision slotting machine with 12 feeds and a maximum stroke of 7⅞ in., and the "Hydroveso" hydraulically driven universal grinding machine.

Exhibits from the **Maag Gear Wheel Co. Ltd.**, of Zürich, included gear-cutting machines, gear-grinding machines, and the model JHSS 75 internal gear grinder. This latter machine was demonstrated in action, grinding the oblique-toothed rim of a planetary gear for an aircraft engine.

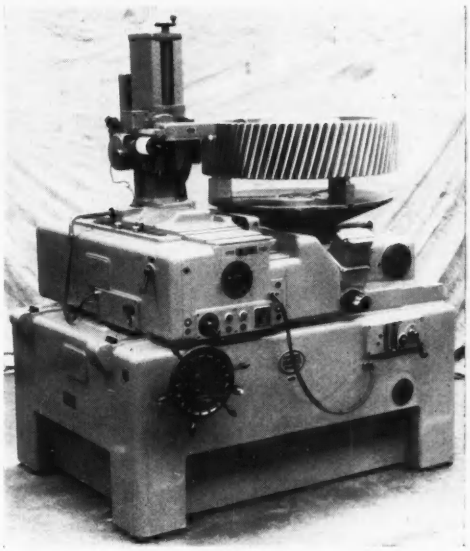

Fig. 43.

Another Maag exhibit was the model PH-100 tooth-profile and helix-angle checking instrument shown in Fig. 43. This gear tester is eminently suitable for inspecting the involute tooth profile of spur gears, helical gears, and worms, and the helix angle of spur and helical gears. Measurements can be carried out on wheels from 14·2 to 39·4 in. base-circle diameter, with pitches ranging from 25·4 to 1·27 D.P. Gears with a maximum weight of 2200 lb can be accommodated. In order to reduce the time for setting a gear to a minimum, the tester is fitted with a standard pitch block and adjustable lever transmission, so that special base-circle discs are not required. The base circle is set to within 0·00004 in. by means of a projection screen located on the saddle of the instrument.

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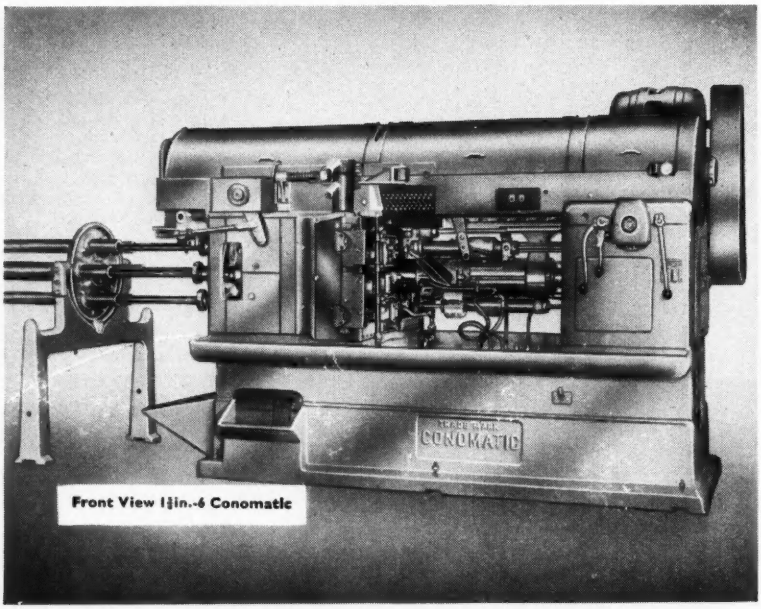

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The new range of Dixi 75 horizontal jig borers exhibited by **Dixi S.A.**, of Le Locle, Switzerland, not only have greater power and accuracy than their predecessors, but have higher capacity and more simplified control arrangements. The microscopes previously used have been replaced by specially developed large and well-illuminated projection screens, on which the divisions of the precision scales used are shown in a central position between double lines. This feature greatly simplifies setting up of the machine and eliminates the need for skilled operators. The screens are equally effective in bright daylight or under reasonably dark conditions, and repeated settings can be made without eyestrain.

The sub-division between two lines on the precision scale is achieved by means of an optical micrometer, optically adjusted divisions of 0·00005 in. appearing on the screens. This micrometer is entirely free from parallax and requires no compensation for wear, as there are no slides to be moved. In addition, a second optical micrometer is fitted, enabling a round datum figure to be provided after setting the component. This can, however, be brought back to a fixed setting for checking purposes, without moving either the precision scale or the slide, thus providing a means of accurate positioning of subsequent operations, without the necessity for repeated use of a complicated datum figure.

The control system has been greatly simplified, each control fulfilling several functions. In the new arrangement, all that is necessary is to pull a lever in the direction in which it is required a given feature of the machine to move, thus rendering operation of the machine quite positive. All slides and motions not in operation are electrically secured against switching on when any given slides are locked.

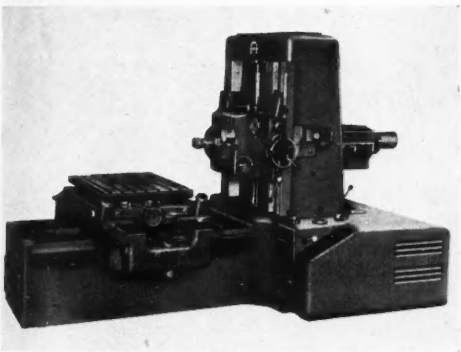


Fig. 44.

The spindle is provided with nine different feeds in either direction, with an automatic stop. A mechanical rapid traverse is also available. Any selected spindle speed is held constant, irrespective of load variations, by means of an 8-hp Ward-Leonard drive. An effective electrical brake is also incorporated, ensuring extremely rapid braking of the spindle.

Various models of the Dixi 75 are available, i.e., with and without end support, and with long or short strokes. Fig. 44 shows the short-stroke model without end support.

In addition to their series " Z " and " Z'44 " milling machines, and a range of their well-known standard semi-automatic lathes, **Saviem**, of St. Ouen, France, exhibited three new types of parallel lathes, i.e., the P–720 and P–1000 screw-cutting and slide lathes and the model F–510 lathe. Of these, the model P–720 lathe embodies a number of special features intended to confer improved qualities of strength and speed. Thus, for example, the slides on the bed have been so positioned as to produce a more equal distribution of internal strains caused in the bed by cutting stress and to impart added strength to the saddle. In addition, the head includes a device for changing speeds while the lathe is operating, not only eliminating manual operations with their consequent waste of time, but, even more important, maintaining a constant cutting speed during the entire cut, irrespective of variations in diameter of the workpiece. The swing over the bed in the P–720 lathe is 28 in., over the saddle 26½ in., and over the carriage 17½ in. Twenty spindle speeds are provided, ranging from 16 to 1250 rpm.

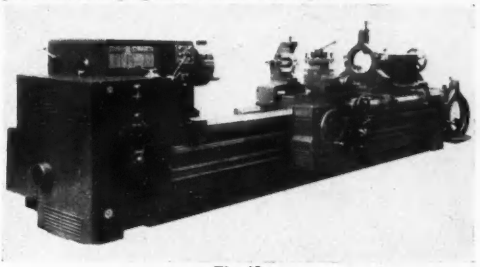


Fig. 45.

The P–1000 lathe (Fig. 45) is similar in general design to the P–720, but has a swing over the bed of 43 in., over the saddle 40 in., and over the carriage 29 in. Twenty spindle speeds are provided, ranging from 6 to 500 rpm.

The model F–510 lathe was produced to meet various needs arising in machine shops. The swing over the bed is 20 in., over the carriage 12¾ in., and over the saddle 18 in., while the cross travel is 12 in. Seventeen spindle speeds are provided, from 40 to 2000 rpm. These large swings and cross travel, combined with the extensive range of spindle speeds and feeds, permit the execution of a very wide variety of turning jobs. The lathe bed, similar in design to those of models P–720 and 1000, is of extremely rugged construction, and all slides are hardened and trued. In addition, the F–510 lathe may be fitted with various accessories, including a rear tool-carrier, a loose headstock for boring, and a copying attachment.

A comprehensive range of testing equipment was exhibited by **Otto Wolpert-Werke**, of Ludwigshafen, Germany, including a new electronic tensile tester, hardness testers, tensile testing machines, universal testing machines, a pendulum impact tester, and a spring testing machine (Fig. 46) for tension and compression tests on coil or leaf springs.

Of these machines, the field of hardness testing was well covered by equipment capable of Rockwell, Brinell, or Vickers tests, including the model HT.1A machine, which covers both Rockwell and Brinell tests, with push-button control for test loads of 15·6 to 250 kg. The measuring device of this particular machine is equipped with automatic zero positioning.

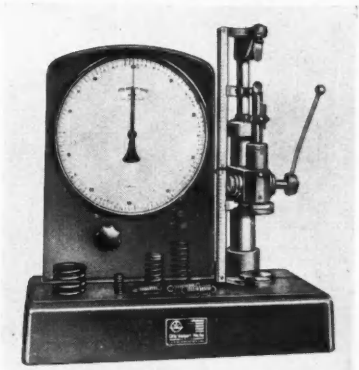
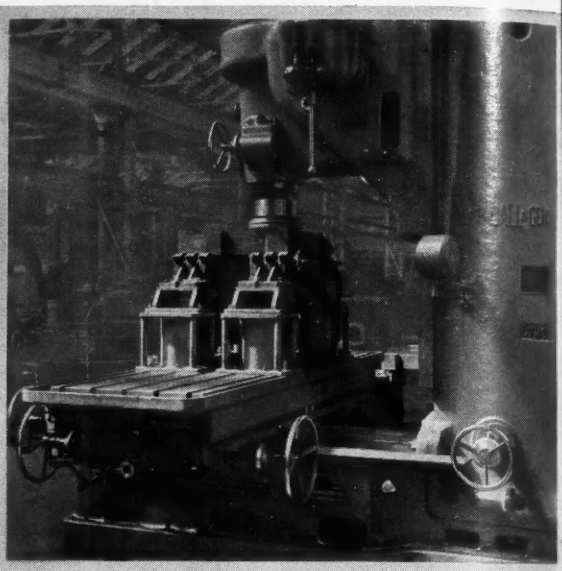
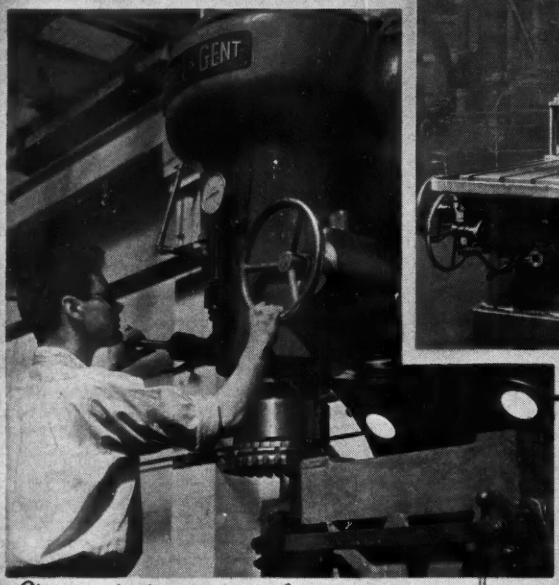


Fig. 46.

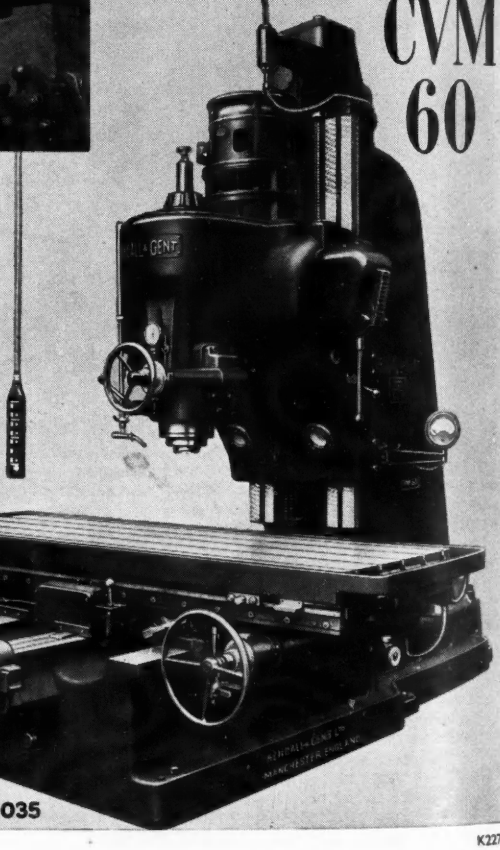
VERTICAL MILLING



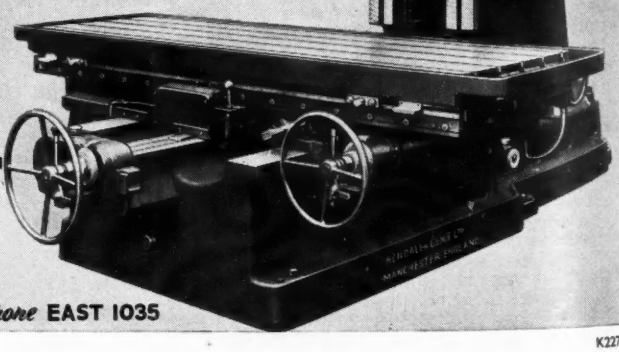


Photographs by courtesy of The Express Lift Co. Ltd. Northampton

WITH THE CVM 60



THE CVM.60 combines maximum production with extreme accuracy and easy operation. Powered by a 25 h.p. or 40 h.p. motor as required, spindle speeds range from 15 to 840 r.p.m. in eighteen steps. Rectangular table type has working surface of 9 ft x 2 ft 9 in, and traverses 7 ft 2 in x 3 ft 3 in, with a choice of four feed ranges. Other models available with circular table or combined circular and rectangular table. Maximum height under spindle nose is 3 ft 5 in.



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Other exhibits included the " Dia-Testor", type 2, which undertakes Vickers and Brinell tests directly, and Rockwell tests with a special attachment. The BS.300 hardness tester, another exhibit, is designed for high-speed Brinell testing, results being shown by light signals. The actual testing process is automatic, the operator merely loading and unloading the testpieces, which, for this machine, do not normally require grinding, as uneven finish has virtually no effect on tests, which are based on a preload of 100 kg.

In addition to their " Centec " No. 2 series precision milling machines, **Central Tool & Equipment Co., Ltd.,** of Hemel Hempstead, Herts., showed their " Centec " 3R fully automatic production milling machine fitted with a new type of programme control which acts not only as a " brain " for each particular programme, but also as a memory device, if it is required to repeat the programme at any future time. With this device, the programme is set simply by positioning buttons in slots on the control slide, and these buttons actuate micro-switches which determine the hydraulic movements of the table and the head. The control slides can be removed and exchanged for different slides with different set-ups in less than two minutes and can then be stored for future use. This feature, which eliminates costly setting-up time, makes these machines very suitable for both long runs and small batches, and the combined head- and table-cycle movements, working automatically to the programme, ensure minimum floor-to-floor time.

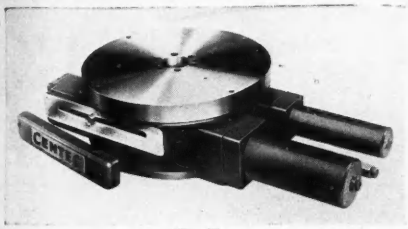

Fig. 47.

Other " Centec " exhibits included a range of newly designed pneumatic vices which eliminate the difficulties inherent in the more conventional types of pneumatic vice, and two auto-pneumatic indexing tables, one of 6 in. diameter and the other of 16 in. diameter. The 16-in. diameter table (Fig. 47), which was exhibited for the first time, permits heavy weights to be mounted on it and is capable of dividing any angle divisible by 3 with a very high degree of precision.

Exhibits from **Cincinnati Milling Machines Ltd.,** of Birmingham, and **Cincinnati-Nederland N.V.,** of Vlaardingen, Netherlands, included a wide range of milling machines and grinding machines. Of these, the No. 5 plain and vertical dial-type milling machines produced by Cincinnati Milling Machines Ltd. are of special interest. These heavily constructed units incorporate many new features and, as they are fitted with automatic table cycles, are fully equipped to take their place in production lines.

The wide, heavily built knees of these machines are independently motorized, an arrangement which simplifies the drive to the knee and saddle table unit, and it therefore follows that maintenance is facilitated. The usual spindle starting and stopping lever has been eliminated and its place taken by a " console " push-button control station in the front of the knee, greatly facilitating operation. On each machine the main drive is by a 40-hp motor, power being transferred directly to the spindle. These machines have exceptionally wide ranges of spindle speeds (from 14 to 1400 rpm) and table feeds (from $\frac{3}{4}$ to 90 ipm).

The set-up of the plain machine was a slab-milling operation to demonstrate the high power available and the rigidity of design. Two mild-steel blocks, one at each end of the table, were machined $\frac{1}{16}$ in. deep at 39 ipm with a 5-in. diameter slab mill, 7 in. in length, while milling in both directions illustrated both climb-milling and conventional milling.

In addition to examples of universal copying lathes, form and cutter-grinding machines, gear planers, and carbide-tool grinders, **The Oerlikon Machine Tool Works Buehrle & Co.,** of Zürich, Switzerland, exhibited their model R.2 production jig borer and their model UB.2 universal drilling machine.

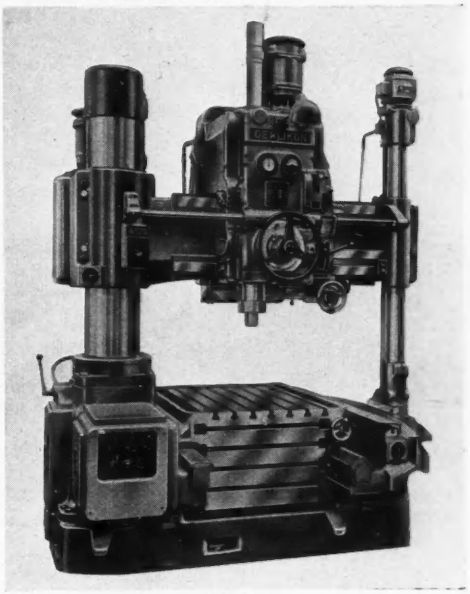

Fig. 48.

Of these, the R.2 production jig borer (Fig. 48) is a heavy-duty machine, which, although fitted with double columns for greater rigidity, is extremely sensitive. The outer column is mounted on ways, so that it can be moved through an arc. Alternatively, it can be positively located and locked for making co-ordinate settings, which can be made rapidly either optically or by means of measuring rods. The quill is clamped electromagnetically with finger-tip control. With a distance of 59 in. between columns and a drilling capacity of $2\frac{3}{16}$ in. in cast iron, this is the smallest of a range of three machines of this type.

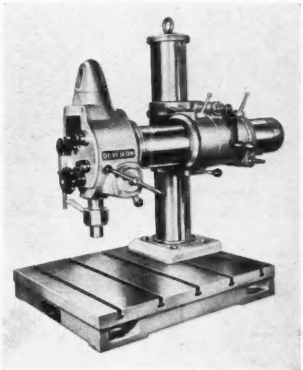

Fig. 49.

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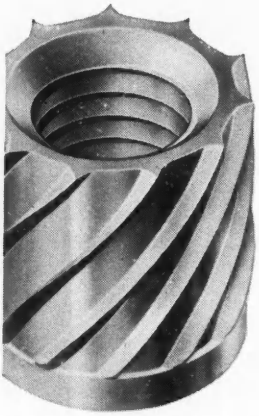

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The UB.2 universal drilling machine (Fig. 49) is designed to combine the functions of a pedestal drill with a drill which is readily transportable to the work in cases where it is not possible to take the work to the machine. The stand and the drilling unit, which can be swivelled to any angle, form two separate sections. The column, 6¼ in. in diameter, is exceedingly rigid and can be mounted in any position on the baseplate, which measures about 36½ × 27½ in. Alternatively, the column can be detached from the baseplate and mounted on the work. The capacity is 1 in. in cast iron, and there are eight spindle speeds, from 25 to 2560 rpm, and three feeds, from 0·0024 to 0·01 in. per revolution of the spindle.

With a maximum capacity of 8 in. diameter, 7 in. face width, and 12 D.P., the Dowding V.8 universal hobbing machine (Fig. 50), exhibited by **Dowding & Doll Ltd.**, of London, W.14, has an indexing range from 6 to 400 teeth, including most prime numbers. Either climb or orthodox hobbing methods can be employed, and the machine is provided with built-in differential gearing, thereby enabling exceedingly accurate helices to be generated and simplifying the set-up for mating helicals. The hob head can be swivelled to 60 deg. in either direction, and ten hob speeds are available by means of conveniently situated pick-off gears which are fully enclosed and constantly lubricated, as also are the index change-gears. Additional equipment includes rapid power return to the hob slide, and a tangential-feed hob head to facilitate the cutting of worms and worm-wheels.

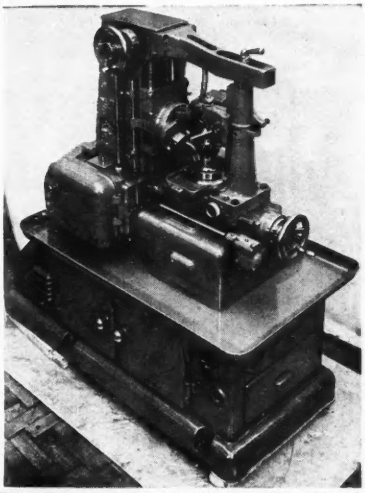

Fig. 50.

Another Dowding & Doll exhibit was the Ahcol "Rotamill" (Fig. 51), which is a semi-automatic machine designed for the continuous milling of slots, flats, faces, and other forms. The parts to be machined are loaded into tooling arranged around a continuously rotating work drum, clamping and unclamping being performed automatically by means of a pressure roller as the components enter and leave the work zone. Alternatively, parts which are awkwardly shaped and difficult to clamp can be held in two or more simple fixtures mounted on the face-plate, and a device can be set to give normal feeds during cutting and fast traverse between stations. In either case, loading and unloading is performed while cutting, and the process is continuous. The face-plate is integral with the spindle, the normal diameter of the work drum being 12 in. Cutters up to 6 in. in diameter can be ganged up to 6 in. wide, and are adjustable endwise. The work-spindle is adjustable towards or away from the cutter spindle, and a graduated collar gives readings of 0·001 in. Cutter spindle speeds of 132, 211, 330, and 528 rpm are available.

Fig. 51.

Other exhibits from Dowding & Doll Ltd. included two models of the British-built Wiedemann turret punch press, which has been developed to provide an economical method of producing components in which a number of holes of varying shapes and sizes have to be pierced. Up to 16, 18, or 20 punches and dies of any shape and size can be fitted to the turrets and rapidly indexed to the working position. Hole location is effected either by means of a simple template, or co-ordinate dimensions can be obtained direct from the gauge table.

Of the two models exhibited, model RA.41P (Fig. 52) can pierce a 16-swg mild-steel chassis with a total of 83 holes varying from about 0·01 to 1⅜ in. diameter, including slots, the largest of which is about 1⅝ in. square, in a floor-to-floor time of under 5 min. Centre-distance location is effected by means of a template in which all the holes are drilled to ¼ in. diameter, a coloured "route" painted on the template ensuring that all holes of the same size and shape are pierced consecutively, and that the turret is indexed the minimum number of times. The model RA.41P machine is available in two sizes, i.e., for sheets up to 24 × 24 in., or 40 × 28 in. respectively. The punching capacity in both cases is 3 in. diameter in 0·074-in. mild-steel plate, 2 in. diameter in ⅛-in. plate, or 1 ⅜ in. diameter in $\frac{3}{16}$-in. plate.

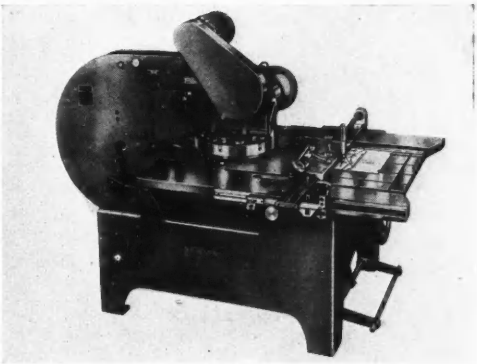

Fig. 52.

The other model exhibited, the R.44, can pierce a total of 67 holes varying from about ⅛ to 1½ in., including a rectangle of about 2 × 1⅝ in. and four corner notches of 1 in. square, in a little over 5 min. This machine, which has the same punching capacity as the RA.41P

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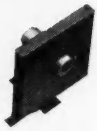

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model, is fitted with a rack gauge table and accommodates sheets up to 72 × 26½ in.

Exhibits from **Rigid Limited,** of Rorschacherberg, Switzerland, included their automatic "Hydrocopy" turbine-blade milling machine, model ST.100/3. This three-spindle machine (Fig. 53) is provided with a vertical and transverse copying device for longitudinal pendulum milling, with and without transverse pick-feed, and for copying by the transverse sweep method with longitudinal pick-feed.

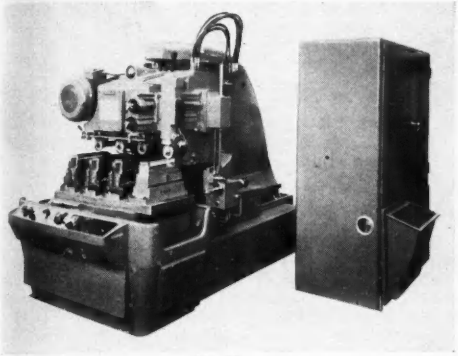

Fig. 53.

In this machine, sixteen spindle speeds are provided, ranging from 20 to 350 rpm. Feeds are steplessly variable, longitudinal feed being from about ⅜ to 20 ipm, and ⅜ to 39¾ ipm transverse. Longitudinal and transverse rapid traverses are provided. The table size is about 35½ × 17¾ in., and the distance between spindle axes is 9½ in.

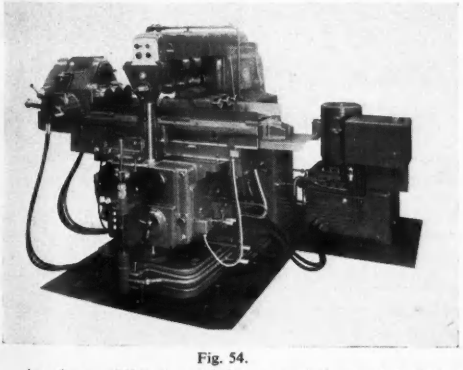

Fig. 54.

Another exhibit by Rigid was their model RK.5 milling machine (Fig. 54), which is a three-spindle machine with an automatic dividing device and hydraulic receding device, a four-station turret head, and an intermittent table cycle control. Eight spindle speeds are available, ranging from 50 to 220 rpm, with twelve longitudinal feeds, from ¼ to 14¼ ipm. Longitudinal rapid power-traverse is provided, the speed being 65¾ ipm. The table, which measures about 67 × 14¼ in., swivels through 30 deg. in either direction. The centre height is approximately 4¾ in., and the dividing-head spindles are provided with a 5¼-in. axial adjustment. The hydraulic vertical table stroke is 2⅜ in.

A new development exhibited by **Eugen Weisser & Co.,** of Heilbronn, Germany, is their "Senior" universal lathe (Fig. 55), which combines exceptional rigidity with versatility and extreme ease of operation. The bed of the machine is exceptionally wide (nearly 20 in.) and is extremely sturdy, and the standard design features hard-

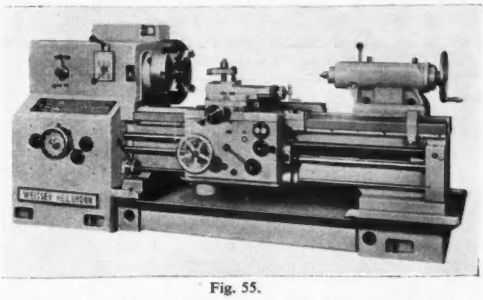

Fig. 55.

ened and ground steel gibs, ensuring almost unobstructed chip removal. The tailstock is also very robust and is an independent unit. The graduated sleeve has a large diameter of nearly 4⅜ in. The main spindle bore has the exceptionally large diameter of about 3 3/16 in.

Eighteen spindle speeds, from 18 to 1400 rpm, engaged by only two levers, are provided, while a graduated dial for forty control steps permits quick setting of feeds and threads. A single-disc dry magnetic brake permits virtually instantaneous stopping of the main spindle, and all controls are conveniently located at the rear of the headstock.

Among a wide range of semi-automatic turning and boring machines featured by **Maschinenfabrik Diedesheim G.m.b.H.,** of Diedesheim, Germany, including their "Frontomat" front-operated semi-automatic turning machines, an interesting exhibit was their model 1 HK "Drebomat" semi-automatic turning and boring machine (Fig. 56), which is designed for machining the cone seating of valve bodies and plugs in bronze. Of the two spindles provided, the rear spindle carries the plug between centres, while the front spindle carries the body in a power-operated chucking-cage which affords the maximum support during the operation. This cage can be changed to suit the particular component to be machined. After loading, and on movement of a lever, the 5½-hp headstock motor drives the spindles through V-belts and anti-friction bearings. The table simultaneously approaches the working position at a rapid speed. At the appropriate point, the feed rate is engaged, and the taper faces are rough-machined during the advance stroke. A micrometer end stop arrests the table, the roughing tools are swivelled clear of the components, and the finishing tools are brought into position. The feed rate is then reduced, the table movement reversed, and the taper faces finish-machined during the return stroke. When the tools are clear of the work, the table rapidly moves to its initial position and the spindles are electrically braked. Since the heads are aligned exactly parallel and are mounted on the same slip-gauge-adjusted swivel base, the components mate perfectly. The tool-holders are controlled hydraulically. The height of the centres is 6½ in.,

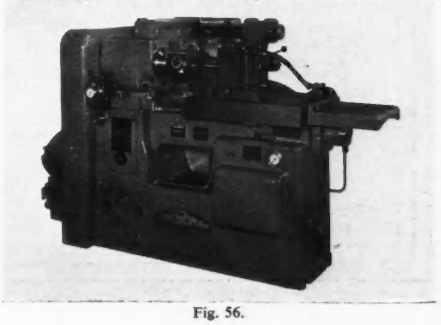

Fig. 56.

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and feeds are steplessly variable from $\frac{3}{16}$ to $9\frac{7}{8}$ ipm. Spindle speed depends on the capacity of the particular machine supplied and varies from 1500 to 3800 rpm. Similarly, the output rate varies from 20 to 80 complete valve pairs per hour, depending on size.

Another " Drebomat " machine exhibited included the model 1/1 for boring taper valve housings and for turning the corresponding plugs. This machine also has a double spindle arrangement, but features a somewhat different tool arrangement and application. This machine can be supplied with suitable fixtures and tooling to accommodate a variety of workpieces; in all cases, suitable arrangements and machining sequences can be supplied on receipt of the requisite part drawings.

Other " Drebomat " machines exhibited were the model AM, which was shown in a special application for producing three-way fittings, and the model UD1, which was shown arranged as a finish-turning machine for precision parts used in office machines.

An exceptionally wide range of equipment was exhibited by the **V.D.F. Group,** comprising **Gebr. Boehringer G.m.b.H.,** of Goeppingen, **H. Wohlenberg, K.G.,** of Hanover, and **Heidenreich & Harbeck,** of Hamburg.

In addition to a range of lathes and gear deburring machines, including the new Boehringer 1367 crankshaft lathe and their model Z400 gear deburring machine, Boehringer exhibited their new double standard planing machine, model 8Z/1000. This machine (Fig. 57) has a pull of 8 tons and, as distinct from previous models, has a cross-rail with four transverse screws. Apart from one transverse screw for the cross movement, each toolhead on the cross-rail has a separate splined shaft for operation of the rise and fall movement. This is a valuable feature on wide planing machines, since the vertical movement of the outer cross-rail toolhead or the reversal of the feed can be controlled from the operator's position. The drive is from a 3-phase variable d.c. motor with Ward-Leonard control. This machine is also equipped with an emergency cut-out, hydraulic over-run stops at both ends of the bed, and an oil-flow indicator with automatic cut-out. The bedways are covered with laminated plastic, assuring long life and a low coefficient of friction. The range of application of this machine can be considerably extended with such items of additional equipment as multi-tool heads, milling attachments, grinding attachments, and tracer-controlled copying attachments. The milling and grinding attachments (the latter suitable for both cup-wheel and peripheral grinding) can be arranged to be interchangeable with the normal toolheads. The reduced table speeds necessary for milling and grinding are obtained through an additional gearbox. The milling attachments are suitable for longitudinal, cross, and vertical milling.

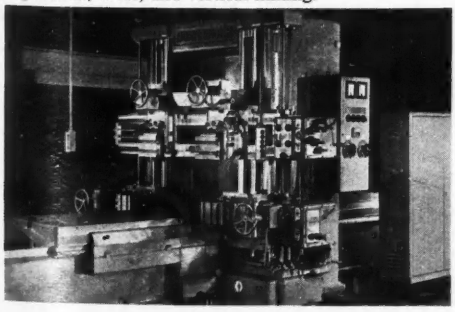


Fig. 57.

The E1400B heavy-duty lathe forming part of the exhibits by Wohlenberg demonstrates a new development introduced by V.D.F. This lathe is equipped with triple bedways, so that the carriages can travel past the steadies and the tailstock. Thus, it is possible to machine long components, particularly crankshafts, without rechucking. This new type of lathe was shown with a centre height of $29\frac{1}{2}$ in. over flat ways, and a maximum turning length of 236 in. Components weighing up to 16 tons can be accommodated without any additional support. There are 24 spindle speeds provided, from 0·9 to 180 rpm, selected by two handwheels on the headstock, the spindle being mounted in three double-row high-precision cylindrical roller bearings. A special feature is the series of safety devices which prevent the lathe being started if the gears are not properly in mesh, or if the lubrication system should fail. Should lubrication fall below a certain level, or the machine be overloaded, the feed is relieved and the spindle subsequently stopped. The entire feed mechanism is accommodated in a gearbox on the carriage, so that the operator can make a selection without having to move from his position. This applies also to the leads where the machine is arranged for screw-cutting. The longitudinal feeds are steplessly variable from 0·012 to 28 ipm, and leads from 1 to 60 mm., and their equivalents in inches are obtainable. The feed motor also operated the rapid power traverse for the carriage at a constant speed of 10 fpm longitudinally and 5 fpm transversely, a brake being provided for accurate control of these movements. The tailstock has a built-in rotating centre, together with a spring overload release and gauge. The entire tailstock unit and the quill can be moved in rapid motion by built-in auxiliary motors.

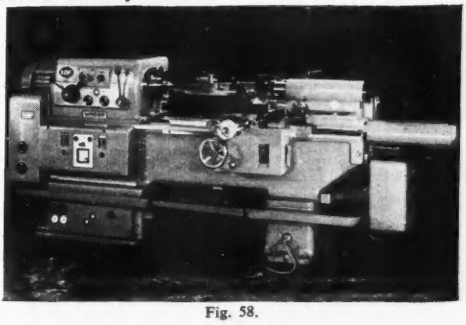
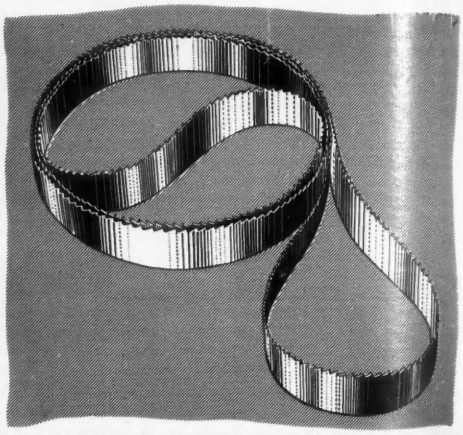


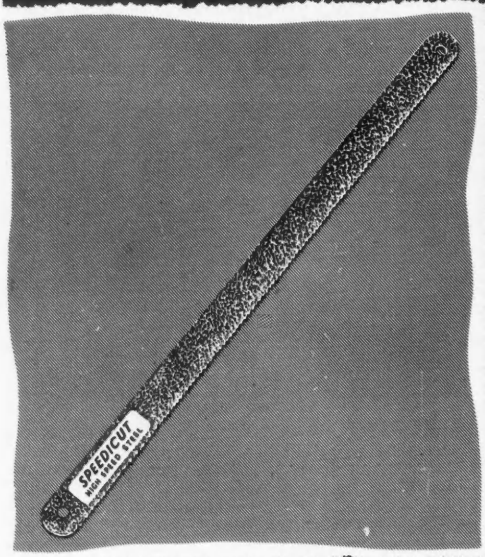
Fig. 58.

In addition to a V.D.F " Unicop " copying lathe, model S500 type I, and a " Unicop " copying lathe, model V3 type III (Fig. 58), two completely new machines in the Unicop range, i.e., models V3 type IV and V5 type IV, were exhibited by Heidenreich & Harbeck. The general principles of both these two latter machines are similar, but the capacities vary. By using an automatically indexing three-way toolpost and the corresponding three-way swivel attachment, the lathe becomes a combined turret and copy-turning machine. Apart from loading and unloading, the cycle is entirely automatic and includes speed and feed changes, as required and preset. An electric power chuck permits the maximum benefit to be derived from the automatic operation of the machine.

These lathes are particularly economical for turning operations which could not previously be performed by the usual copying methods, such as components requiring the use of the multi-stage technique. Turret copying permits several tools to be used almost as easily as one. By using a tailstock, the lathes will copy longitudinally in accordance with a preset cycle, or without the automatic control. The V3 type IV was shown copy-turning a brake cover requiring four tools to be used for the rough machining of one side, and the subsequent form-copying of each contour. The V5 type IV was shown finish-turning a casing cover, previously rough-turned on a Boehringer turret lathe, only one operator being required for the supervision of both rough- and finish-turning with the two machines.

SPEEDICUT





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Both machines have a copying length of 29½ in. and steplessly variable transverse and longitudinal feeds from 0 to 0·04 in. per revolution. Model V3 type IV has a turning diameter over the bed of 20½ in., and a copy-turning diameter over the carriage of 20⅝ in. The height of the centres over flat ways is 10 in., and twelve spindle speeds, steplessly variable between 22·4 and 710 rpm, are provided. Model V5 type IV has a turning diameter over the bed of 26 in., and a copy-turning diameter over the carriage of 15 in. The height of the centres over flat ways is 14 in., and sixteen steplessly variable spindle speeds, from 11·2 to 560 rpm are provided.

The " Sykomatic " magazine-loading gear generator, a totally new development from **W. E. Sykes Ltd.**, of Staines, Middlesex, was exhibited for the first time. This machine is equipped with angular cutter relief and an automatic loading device fitted with a rotary turret magazine to hold a number of components, the model shown having a magazine for holding twelve automobile lay-shaft gears. A detail of the cutter head and turret is shown in Fig. 59.

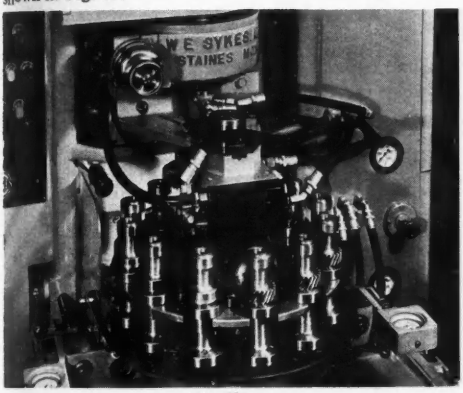


Fig. 59.

The turret, which is loaded with a full complement of blanks, permits fully automatic and uninterrupted operation of the machine for nearly 40 min, the cycle time for each gear being a little over 3 min. Loading itself is particularly simple, as the blanks are easily and rapidly pressed into the spring clips provided. The main-fixture base is bolted to the saddle, and a heavy vertical column supports the indexing magazine and a top plate, which carries the tailstock and indexing piston and is fixed to the top of the column. A hydraulic piston and a dead-stop are provided to lock the fixture at the correct centre-distance position.

The magazine is free to rotate and slide on the column. A spur gear is fixed to the upper part of the magazine, and rack teeth are cut in the indexing piston rod. The chuck is of the expanding-mandrel type and is bolted to the work-table. With the magazine fully loaded, the index piston forward, the magazine up, and the chuck released, the cycle start-button is pressed. The tailstock moves down to enter the bore of the component and continues its downward movement, taking the magazine with it and pushing the work onto the chuck. When the gear is hard against the locating face of the chuck, the latter is operated by a sequence valve to clamp the work. The index piston moves to the rear, the cutter and coolant motors start, the component is fed towards the cutter, and the normal gear-shaping operation commences. During infeed of the saddle, oil at low pressure is applied to the clamp to give additional support to the fixture. When the gear is at the correct cutting depth, oil at high pressure is applied to the clamp, and the fixture is locked for the final cut. After the gear has been cut, the clamp is released, the saddle retracts, and the cutter-motor stops. The chuck is released, and the tailstock and turret move up to lift the component clear of the chuck. The tailstock continues upwards until it is clear of the work, when the index piston moves forward. The rack teeth engage the magazine spur gear and index the next component to the loading position, when the cycle restarts.

The " Codicop " lathe with punched-card control, exhibited by **Le Progrès Industriel**, of Loth, near Brussels, is a new type of production lathe developed to meet the increasing demand for automation. A special feature of this machine is its adaptability to small-, medium-, or large-batch production, with a performance equalling several semi-automatic turret lathes. The punched-card control system employed provides a virtually unlimited range of automatic operating sequences and reduces setting up to a minimum.

The machine can be fitted with four independent detachable tooling units, which can be operated in any required sequence. Each unit on the turret station automatically engages the spindle speed previously selected for it. The basic construction of the machine is particularly suitable for programme work, and the arrangement of the electro-hydraulic elements controlling the detachable mechanical units is extremely practical. These features ensure that all the advantages of an automatic-cycle machine are incorporated in the design and result in increased output, especially with small batches.

Basically designed for the optical and fine-mechanical industries, the " Piropta 120 " turret finishing lathe, exhibited by **Pittler Maschinenfabrik AG**, of Lange, Germany, lends itself particularly to the machining of components which require a very exacting standard of accuracy and a surface finish of less than one micron surface roughness, and which have a single- or multi-start thread of maximum precision.

The machine (Fig. 60), which is manufactured under licence from Zeiss, is equipped with a lightweight 8-station tool turret, steplessly variable spindle speeds from 315 to 2800 rpm, and a semi-automatic thread-chasing attachment which enables single-start threads and threads with a maximum of 36 starts to be cut rapidly. The chuck capacity is 8 in. diameter, and the headstock spindle is mounted in anti-friction bearings.

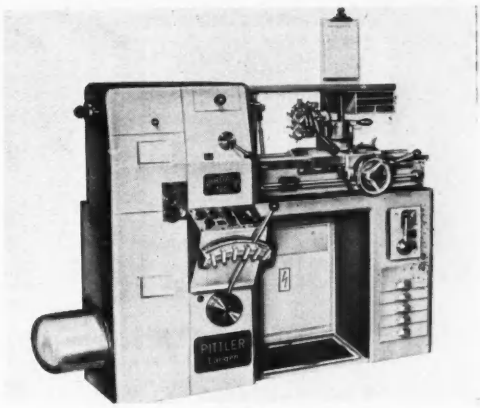
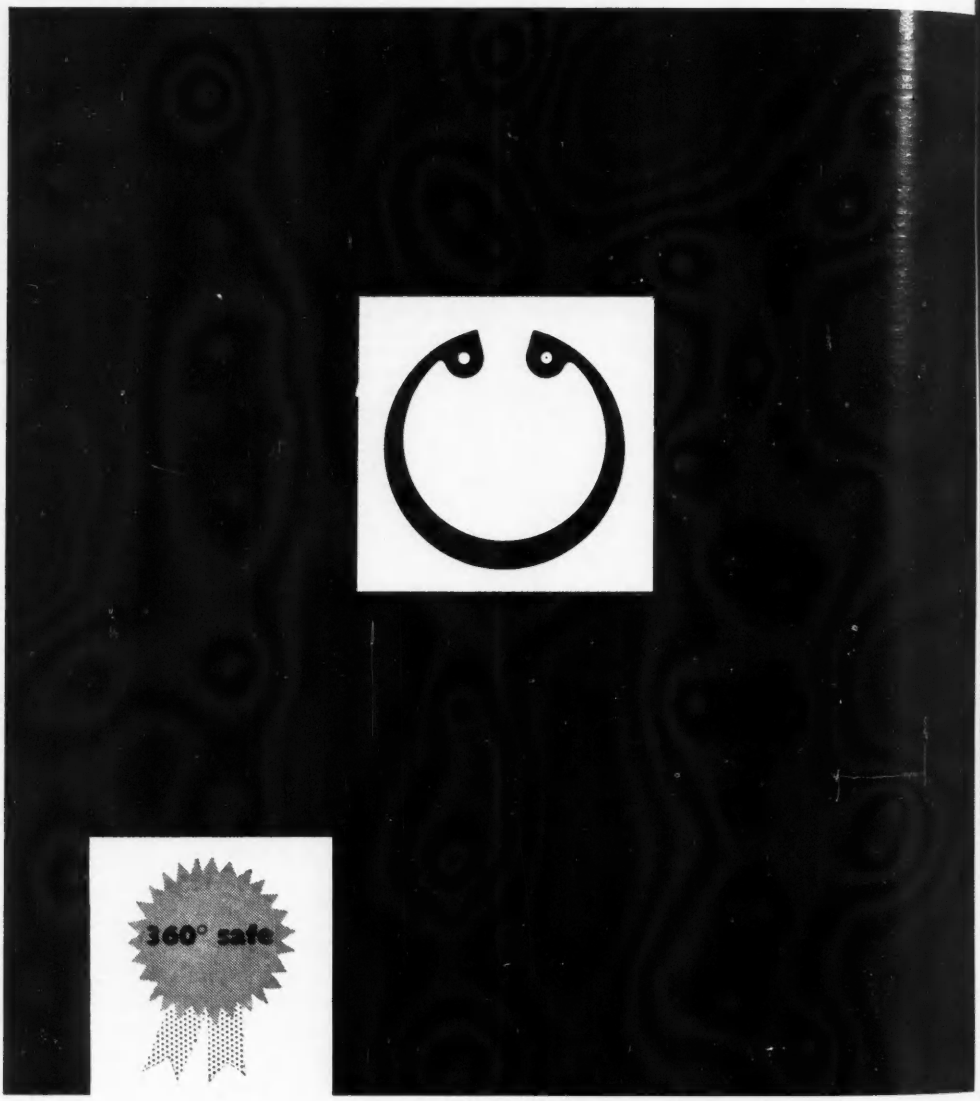


Fig. 60.

Spindle speeds are set by means of hand levers, and the machine is driven by a flange motor, which is mounted inside the base and connected directly to the infinitely variable gear mechanism. The drive unit is attached to the floor, and is thus separate from the machine frame, so that oscillations appearing in the drive are kept away from the machine. The workspindle runs in slide bearings and is driven by belts, the bearings being automatically lubricated by a special oil-circulation system.



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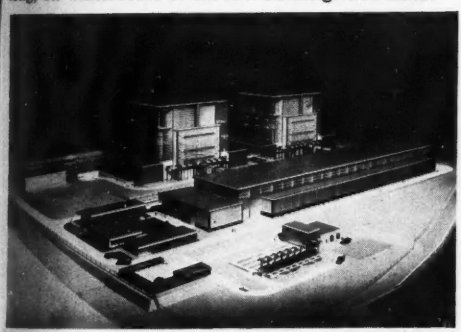
Hinkley Point Nuclear Power Station

The world's largest nuclear power station, to be built at Hinkley Point, Somerset, by the English Electric–Babcock & Wilcox–Taylor Woodrow Atomic Energy Group, is designed for a net electrical output of 500 MW, i.e., nearly seven times the capacity of Calder Hall "A" power station. Erection is expected to start towards the end of 1958, and completion of the station, which will be the first to generate electricity at a cost comparable with that of conventional power stations, is scheduled for the end of 1962.

One requirement of the new £60,000,000 station will be tunnelling under the Bristol Channel from a water-intake structure about 2200 ft offshore, through which water will be circulated to the turbine-house. The pump-house will be inside a mass concrete seawall, nearly 3000 ft in length. For the whole of the power station and ancillary works, Taylor Woodrow will place 300,000 cubic yards of reinforced concrete, requiring about 12,000 tons of steel reinforcement and 400,000 tons of aggregate. About 750,000 cubic yards will be excavated and used to reclaim an area of foreshore, 250 ft wide and up to 3000 ft long, on which some of the new buildings will stand.



Installations, including two graphite-moderated gas-cooled reactors, rising to 175 ft above the foundations, twelve heat exchangers, and six turbo-alternators, will be built in a system of rectangular blocks with various forms of cladding—the steam-raising units in clear glass, the turbine-house in aluminium sheeting, and the administration buildings in coloured enamelled sheeting or plyglass. The pressure vessels will be housed in biological shields with reinforced-concrete walls of dodecagonal shape, 7ft thick, rising over 90 ft from the reactor foundations and with internal diameters of over 75 ft. Surmounting each shield will be an 11-ft thick slab of concrete, and each will be contained in rectangular concrete envelopes of about 140 by 100 ft. Concrete of special density and a particularly high accuracy in placing are required.

The structures fall into two main groups, the reactor/turbine and the administration groups. In the first group, the turbine-house lies parallel with the two reactor buildings and is so sited that their two charge-equipment buildings will face the turbine-house, and their four rows of steam-raising units will be each "end on", for the efficient passing of steam mains, cables, and services between the reactors and the turbine-house. Three heat exchangers and their related blower-house will be grouped on either side of the two reactors, with two cooling ponds behind. A workshop block is planned to be an integral part of the turbine-house.

The turbine-house and the two reactor buildings are arranged about a common centre line, with parallel axes, and the turbine-house, partly on the existing foreshore, will also be parallel with the coast line. The turbine-house building, 704 ft long by 132 ft wide, will be flanked on one side by a transformer annexe and on the other by a mechanical and electrical annexe. Two cranes of 150-ton and 40-ton capacities, will travel the length of the turbine-hall. The control building will be on the reactor side of the turbine-house, and will be adjacent to the reactor change rooms. The control-room is 70 ft by 60 ft in plan, and the building is designed as a separate structure from the turbine-house in order to reduce the transmission of vibration and noise.

The second, and smaller, group of buildings, consists of the administration and welfare buildings, with a canteen between, grouped round a rectangular garden. Covered ways will connect the administration and the welfare buildings to the canteen, with another covered way to the workshop block in the reactor group. The administration building, two-storied, will be 140 ft by 43 ft.

Portable Dry-Powder Fire Extinguisher

Capable of extinguishing various types of fires, including those caused by electrical equipment and by inflammable liquids of all kinds, including alcohols and industrial solvents, the "Nu-Swift" dry-powder fire extinguisher announced by Nu-Swift Ltd., of Elland, Yorkshire, weighs only 10½ lb fully charged and measures about 4 in. in diameter by 16 in. in height, yet is capable of quelling a petrol fire of 14 sq ft in area. Operation is extremely simple, and the fitting of a pressure gauge ensures knowledge as to whether or not the extinguisher is charged and ready for action.

When a knob is struck, a fan-shaped cloud of powder, 4 ft wide and 2½ ft deep, is expelled through a nozzle, the range in still air being 10 ft at 65°F. The high extinguishing capacity of the unit is due to the nature and preparation of the dry powder used, combined with the method of expulsion, which is so contrived that an excess of powder in any part of the cloud is avoided. The powder consists of a number of chemicals, of which the principal is sodium bicarbonate. The powder is held, with dry carbon dioxide, in the sealed pressure container, and is unaffected by atmospheric humidity. The operating head of the extinguisher is a heavy chromium-plated, hot brass pressing, containing the striking knob and nozzle. A strong rubber carrying-handle, of pistol-grip shape, facilitates accurate aiming at the heart of a fire. The total discharge time is 8 sec, and the extinguisher can be recharged in 30 sec, the normal powder content being 4 lb and the CO_2 1·27 oz.

Automatic Pressure Butt-Welding Machine for Steel Pipes

An automatic pressure butt-welding machine, recently built by Metropolitan-Vickers Electrical Co. Ltd., of Trafford Park, Manchester, is the first commercial machine to be manufactured utilizing a process developed by the British Admiralty for the high-quality butt welding of steel pipes. The new machine is intended for workshop use and is designed to produce high-quality butt welds in low-carbon and low-alloy steel pipes in sizes from 3 in. bore × $\frac{3}{16}$ in. wall thickness up to 6½ in. bore × ½ in. wall thickness. Modified designs can, however, be supplied to cater for welds in other ranges of tube sizes. Joints can be made between pipe and pipe, and also

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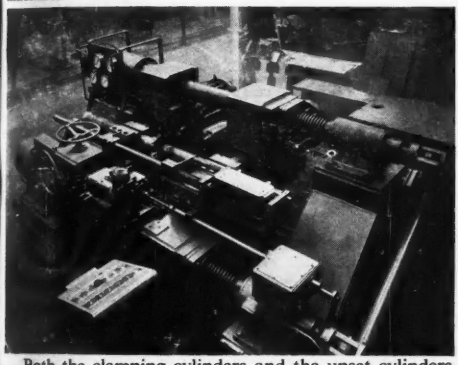
between pipe and pipe flange, by the use of a suitable adaptor plate. Welding times are comparatively short, from 45 sec up to 4 min, depending on the cross-sectional area of the pipe wall. The resulting weld has a smooth, compact upset section, so that for most applications it is unnecessary to remove either the internal or external upset.

Essentially, the process consists of bringing the prepared faces of the pipe ends together under a minor load and heating the joint by means of a multi-jet oxyacetylene oscillating ring burner until a preset thermal expansion is reached. A second higher (or control) load is then applied to return the pipe to its original length when the final upset load operates to complete the weld. All sequences are controlled automatically by limit switches which are also arranged to control the upset and to cut off the gas supply just before the completion of the weld. Post-heat treatment is required and consists of normalizing for low-carbon steel pipes, and normalizing and tempering for low-alloy steel pipes, where air-hardening tendencies are present. Straight normalizing can be carried out in the machine.



Both the clamping cylinders and the upset cylinders are supplied from a self-contained hydraulic system. The system is designed to give independent adjustment for each stage of the three-stage pressure cycle, i.e., initial pressure, control pressure, and upset pressure. The water-cooled multi-jet oxyacetylene burner ring is mounted on a roller carriage which carries the motor for oscillating the burner ring circumferentially and also incorporates means of adjusting the burner ring to be concentric with the weld. It is connected mechanically to the moving clamp through a half-speed device, so that the centre line of the burner ring is always kept on the centre line of the weld. The operator's control desk, which is floor-mounted, contains all the electrical controls required for the normal operation of the machine and also those associated with preliminary tests when changing over from one size of pipe to another. It also houses the special gas-control and mixing unit and the gas-flow indicators.

Control System for Industrial Plant

Originally developed by the British Iron and Steel Research Association, of London, W.1., for use in steelworks, a new control system, designated "Translator Control", has potential application to a wide range of other processes. In many industrial processes, human operators have to translate information given, for example, by dials and gauges into instructions which are then transmitted to the machinery under their control, usually by manual operation of levers or switches. The new control system is essentially a programme store, in which the correct programme for any known condition is automatically and instantaneously presented for use.

The device itself stores all possible useful programmes which may, for instance, in the case of the rolling of steel ingots, take the form of 150 complete screwdown rolling schedules. The operator merely sets four input switches and presses a button, causing motor uniselectors in the translator to present the particular schedule relevant to the information on the input switches. Repeated pressing of the "next pass" button then produces the complete sequence of operation for that schedule.

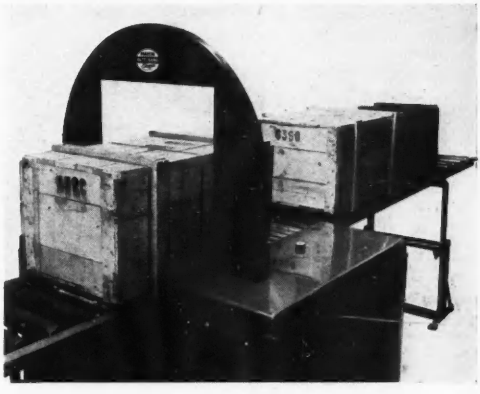
There are many operations in other industries that follow a similar pattern to the above operation, and the translator principle is flexible enough to be adapted to widely varying requirements. Translator control can, in fact, be applied to almost any process in which programmes of sequence operations have to be carried out in accordance with prescribed conditions. The larger and more complicated the equipment to be controlled, the greater are the benefits to be obtained by using translator control. The system offers a means of increasing production without installing expensive new plant. Furthermore, it is of robust and simple construction, being made mainly from motor uniselector switches of the type used in telephone exchanges. The total cost is not high, so that it is quite feasible to provide a complete spare translator, to permit immediate replacement should any fault occur.

Automatic Band-Strapping Machine

Stated to be the only machine of its kind in the world, the "Pakseal" fully automatic band-strapping machine, produced by The Package Sealing Co. Ltd., of Ealing, London, W.5, can be operated at a speed of over 800 ties per hour, representing more than 6000 cases per day by one operator, i.e., at a speed which is five times faster than conventional hand strapping. Furthermore, as the machine is located in the normal roller-conveyor line, cases arrive and are strapped without physical effort on the part of the operator.

With this machine, the tension of the band is preset, and an even tension is applied around all packages, irrespective of their size or shape or of the order in which they arrive at the machine. Both $\frac{1}{2}$-in. and $\frac{3}{4}$-in. band strapping can be handled, and the machine makes its own seal automatically from a coil of special seal strip carried inside the machine and providing 6000 seals at one filling. Automatic locking takes place when the coil of seal strip is exhausted, making it impossible to operate the machine until a fresh coil has been inserted. The seal strength is approximately 85 to 91% of the strength of the strap itself.

The machine, which can handle all types of boxes, cartons, cases, etc., varying in size from 8 in. wide × 4 in. high to $18\frac{1}{2}$ in. wide × 20 in. high, can be maintained without removing it from the assembly line. The top plate can be removed in a few seconds by undoing two screws,



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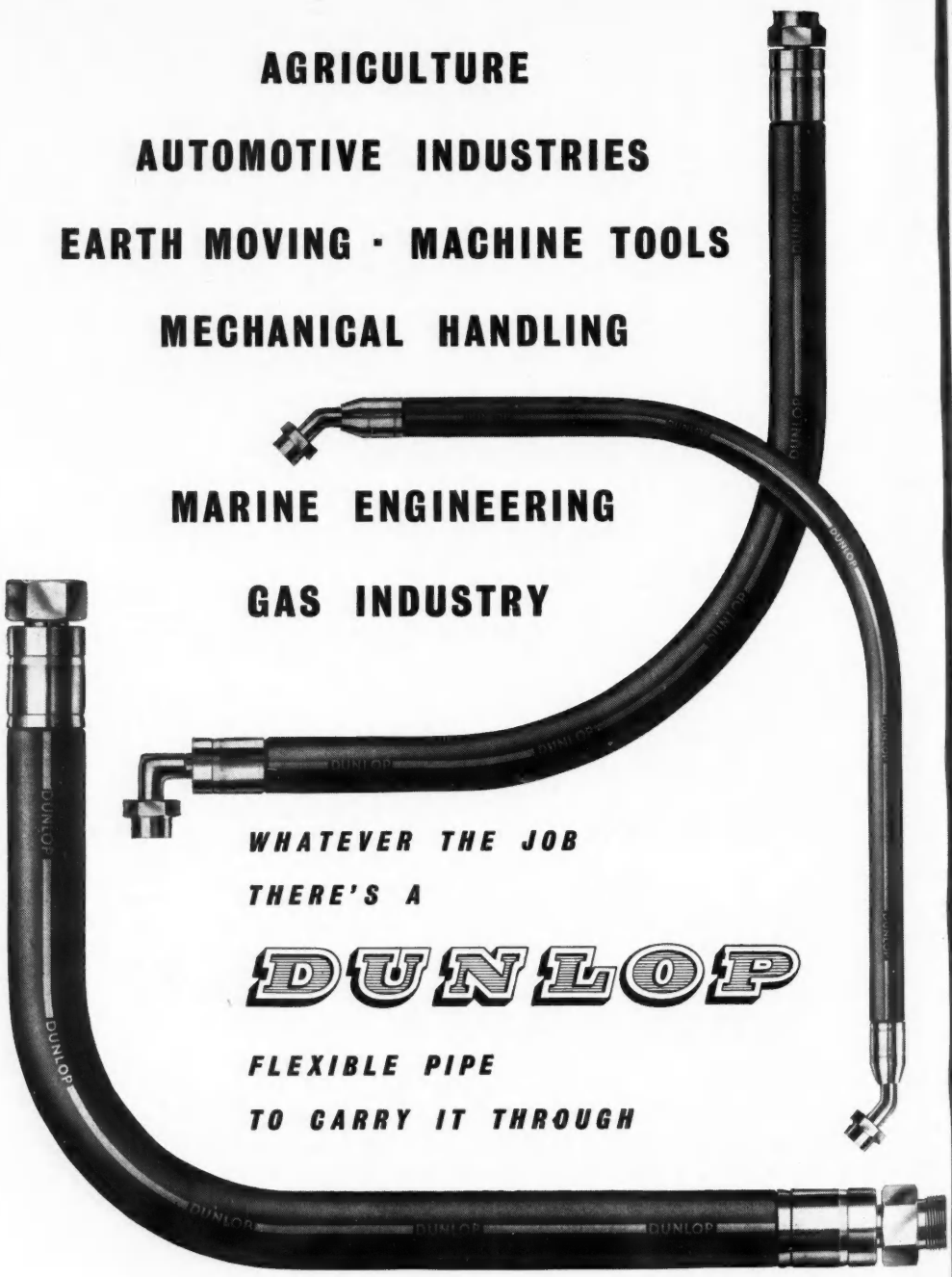

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giving full access to the internal mechanism, and automatic lubrication is provided for all internal parts. Another important feature is a safety device which prevents the operator from applying a strap until the application of the previous strap has been completed.

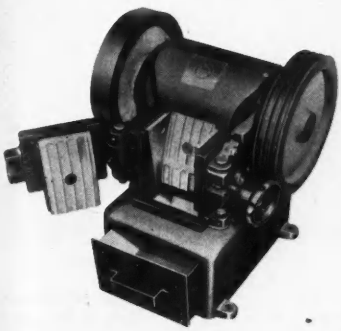
Ultrasonic Cleaning Bath

A new type of ultrasonic cleaning bath, the L.276, for small components and precision parts is announced by Mullard Ltd., of London, W.C.1. A feature of this equipment is a new design of low-frequency radial transducer, which has the advantage of effectively focusing cavitation intensity in the centre of the cleaning-fluid container, i.e., where the component is situated. Another advantage is that the cavitation effect is directed equally to all sides of the component simultaneously ; as a result, unless exceptional requirements call for multi-stage processing, the entire surface area of the article can be cleaned with only one dip. The radial transducer incorporated in the L.276 is a low-frequency type, operating at 20 kcs.

As a result of the special construction of this cleaning equipment, hot solvents may be used directly. The fluid container (a standard Pyrex glass beaker) and the transducer are contained in a water jacket. The water serves not only to cool the transducer, but also to couple the ultrasonic energy to the cleaning fluid. The 250-ml beaker is easily removable, and stands in position in the centre of the transducer annulus ; multi-stage processing with a variety of cleaning agents, when exceptionally high cleanliness is required, can therefore be carried out by simple substitution of beakers. Furthermore, since only the beaker is in direct contact with the fluid, no problems arise in connection with the cleaning of the equipment.

Laboratory Jaw Crushers

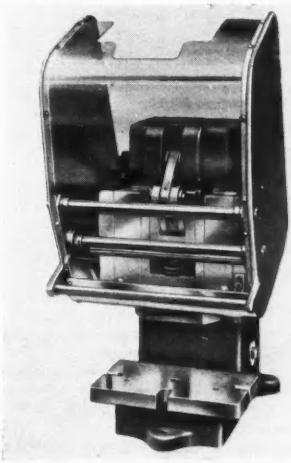
Available in two sizes, the new laboratory jaw crushers produced by Knapp and Bates Limited, of London, W.C.2, combine compactness with maximum strength. Thus, the frame is constructed of a special aluminium alloy, while all crushing or wearing surfaces are made of chrome stellite. The No. 1 size machine, with a capacity of 250 lb of granite per hour, has a jaw opening of $3\frac{1}{2} \times 2\frac{1}{2}$ in. and requires from $\frac{1}{2}$ to 1 hp to run at 450 rpm. The No. 2 size machine has a jaw opening of $4\frac{1}{2} \times 3\frac{1}{4}$ in. and requires from $1\frac{1}{2}$ to 2 hp to run at 400 rpm. Both units may be arranged for a belt drive with fast and loose pulleys or with a direct V-belt drive.



The eccentric movement, located at the top of the moving jaw, is enclosed in a sealed oil bath, permitting a constant discharge opening, ensuring a uniform product, and eliminating the need for regrinding the crushed product. The fixed jaw is fitted to a hinged door which opens outwards, providing easy access for cleaning down after a sample has been crushed. A further feature is a tightly fitting drawer into which the crushed product is discharged to eliminate loss of samples through escape of dust. Jaw setting is effected by a handwheel control.

Pneumatic Bench Presses

Based on a design produced by Morphy Richards Ltd. for use in their own works, a compact pneumatic bench press, with a capacity from $\frac{1}{2}$ to $1\frac{1}{2}$ tons, is announced by Kerry's (Engineering Co.) Ltd., of London, E.10. Occupying a space of only $10 \times 13\frac{1}{2} \times 15\frac{1}{2}$ in., the press has a stroke of $1\frac{3}{16}$ in., a throat depth of $2\frac{1}{2}$ in., and a $7\frac{1}{2} \times 4\frac{1}{2}$ table.



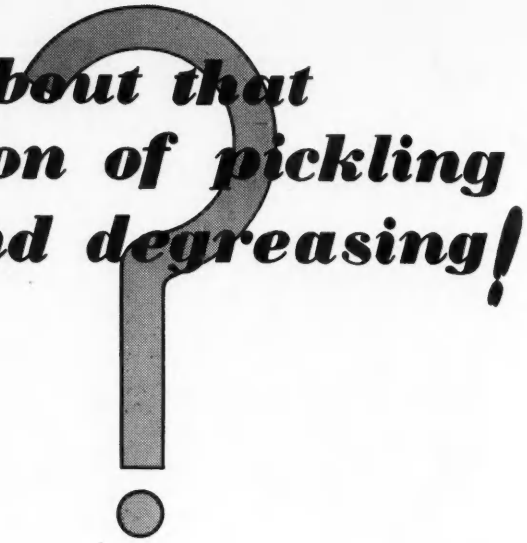
This equipment is suitable for blanking, riveting, piercing, or broaching operations, and can handle many operations normally carried out on a small hand-operated fly or toggle press. It can be supplied as a guard-, foot-, or hand-operated unit, and the pneumatic cylinder can take its supply from the air lines used for the operation of other pneumatically powered tools.

Chromium-Molybdenum Low-Alloy Welding Electrodes

Three new chromium-molybdenum welding electrodes which deposit weld metal of greater creep resistance and corrosion resistance than normal mild-steel electrodes are announced by Quasi-Arc Limited, of Bilston, Staffs. These electrodes (respectively 1% Cr, $\frac{1}{2}$% Mo; $2\frac{1}{4}$%Cr, 1% Mo; and 4-6% Cr, $\frac{1}{2}$% Mo) have been specially designed for applications for each type of alloy steel, and the weld-metal compositions have been carefully balanced to provide satisfactory creep resistance. In addition, they have good welding performance in all positions, with a quiet arc action and easy slag control and detachability. Fully extruded, they have coverings of a basic character, giving a weld metal of a notably fine-grain structure and a very low gas content. The hydrogen content of the weld metal is much lower than the maximum allowed by the AWS/ASTM specification, and sound weld metal to Class 1 radiographic standards can be deposited in all positions. On general fabrication work, it is possible to build up quite heavy cross-sections of weld metal in one run.

These electrodes are available in sizes from 12 to 6 swg, and are suitable for d.c. welding or for use with an a.c. supply. As a protection against moisture, they are packed in cardboard tubes and enclosed in polythene envelopes which are then packed in strong cartons.

What about that question of pickling and degreasing!



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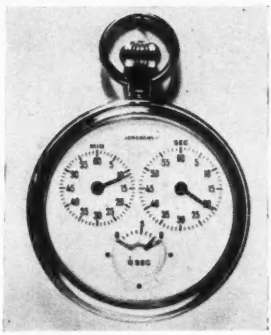
Multi-Dial Stop-Watch

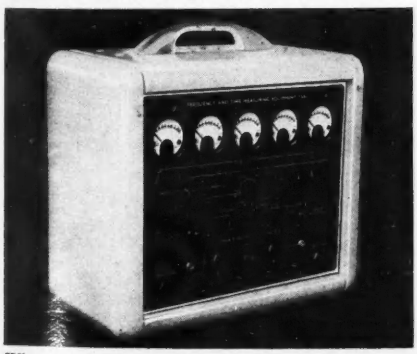
A new type of stop-watch for accurate timing operations, in which results are registered in minutes, seconds, and tenths of a second on three separate dials, is announced by Industrial Timing Instruments, of London, E.C.1. By virtue of the use of different dials, readings are greatly facilitated and, in fact, misreadings cannot arise. Thus, for instance, the time shown in the illustration is manifestly 10 min 20·8 sec. Accuracy of recording is another important feature, inasmuch as the decimal hand cannot stop between strokes on the split-second dial, so that dead-on register is always obtained.



Shockproof and fitted with a seven-jewel lever movement, this sturdily constructed instrument, designated the T.D.50, will time operations up to 61 min. The usual starting and stopping sequence employed in stop-watches is retained, i.e., initial pressure on the button starts the hands, a second pressure instantly stops them, and a third pressure returns them to zero.

Transistorized Frequency- and Time-Measuring Equipment

The production of transistorized frequency- and time-measuring equipment incorporating plug-in units is announced by Venner Electronics Limited, of New Malden, Surrey. This versatile equipment is capable of measuring any frequency in the range between 10 cps and 50 kcs, the period of any wave-form from 0·00001 cps to 10 kcs, and the time-interval between two consecutive pulses from the same or independent sources from 0·0001 sec to 11½ days. It can also be used to determine the open or closed time of a pair of contacts in the same time range. Digital presentation is employed, the indicator for each decade being a meter calibrated from 0 to 9.



When set to measure frequency, any of three gating times may be selected, i.e., 0·1, 1, or 10 sec. The count of the unknown frequency will then be carried out for any of the selected periods. In this way, the frequency to one decimal place may be determined. Six standard output frequencies are available, and any of the six frequencies may be measured by depressing the test switch. An automatic timer is fitted, so that repetitive measurements may, if desired, be made without the equipment being operated by hand. The display time is variable from 0·5 to 5 sec.

When set for period measurement, the internal 10-kcs crystal oscillator is counted for the duration of one input cycle of the unknown frequency. In this way, an extremely high order of accuracy can be obtained for frequencies of from 0·00001 to 100 cps. Once again, the display timer may be employed, enabling repeat counts to be made. The test switch is still operative, permitting the internal reference frequencies to be injected.

With the equipment set for pulse-interval timing, the two inputs provided become operative, and a pulse fed to the start socket opens an internal gate, permitting the feeding of any of the six internal frequencies to the counting stages. A very wide range of timing can be carried out with optimum accuracy obtained at all times. As before, the display timer may be made to operate, so as to hold the indicated elapsed time for an adjustable period between 0·5 and 5 sec, at the end of which it resets all decades to zero, awaiting another start impulse.

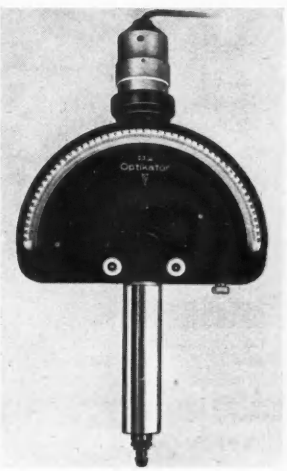
The contact timing position on the function selector enables ten different types of timing to be carried out from virtually any combination of contacts. It will, for example, measure the closed or open time of a single pair of contacts, or the interval between one pair of contacts closing or opening and another pair of contacts opening or closing. Here again, any of six internal time bases may be selected.

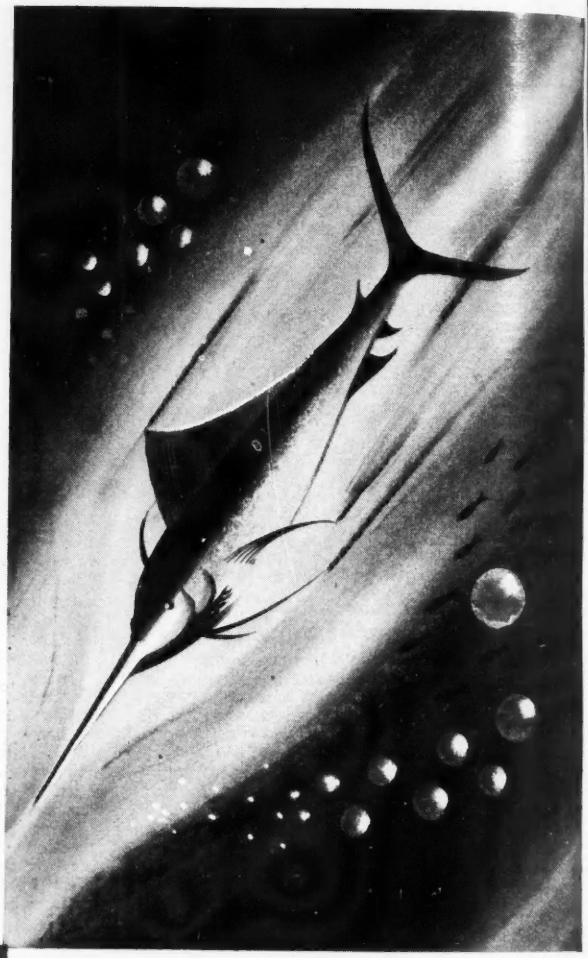
Fine-Limit Contacting Indicator

Representing an improvement on their "Mikrokator", the new "Optikator" fine-limit contacting indicator manufactured by VEB Feinmesszeugfabrik Suhl, of Suhl/Thüringen, Germany, is now available in the U.K. from the agents, the Mortimer Engineering Co., of London, N.W.10.

In the "Optikator", motion of the contacting pin is indicated, via an optical-mechanical system giving magnifications of × 5000 and × 10,000, on a scale, an inertialess beam of light being used as a pointer. The low-voltage filament bulb used for illumination is fed from a mains-operated transformer and is housed in a casing which is specially designed and insulated to prevent transmission of heat to the measuring elements.

A novel feature of the optical system used is the provision of optical tolerance marks, which are adjustable over the entire measuring range. If the specimen differs from the prescribed tolerances, the luminous pointer will flash with a green colouration if the difference is positive, and red if the difference is negative. These tolerance marks are easily set by two knurled screws on the front of the instrument. By means of a conveniently located adjusting screw, the scale can be accurately set within a range of 10 scale divisions, so that the instrument can be adjusted readily and accurately to zero. Another advantage is the provision of a lifting lever, which enables the measuring pin to be set gently on the specimen and which is self-locking in its terminal position, so that the next specimen can be conveniently located in the position best suited to the measurement involved.





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ADDITIONAL ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

The Application of Cable in Cathodic Protection.
By M. A. RIORDAN and R. G. FISHER. (From *Corrosion, U.S.A.*, Vol. 13, No. 8, August 1957, pp. 48–54, 5 illustrations.)

THE use of cathodic protection has been economically justified as an effective method of reducing corrosion losses on underground and underwater metallic structures. In connection with economic considerations, the objective in design of a cathodic protection system is maximum effectiveness at optimum overall costs. Therefore, all components of the cathodic protection system are subject to technical and economical analysis in the design phase. Cable is usually a fundamental component of a cathodic protection system. This paper is concerned with the technical and economic factors involved in selection of cable for the particular applications involved in cathodic protection.

The requirements of a suitable metallic conductor in a cathodic protection system are detailed. Particular attention is paid to economic factors and to power loss in the selection of suitable conductors and the most satisfactory cable sizes. Data are given to show the relative electrical resistivity of copper, aluminium, iron, and lead.

The selection of cable insulation and protective coverings in cathodic protection systems is discussed in detail. Data are given to show physical and accelerated ageing requirements of polyethylene insulation and polyvinyl chloride sheath compound. Data also are included to show the electrical stability of various types of insulation after immersion in tap water and in various chemicals. Other topics include the mechanical properties of insulation, insulation versus environment, installation techniques, and splicing requirements.

It has been found that a cable construction which makes use of a polyethylene insulation and a polyvinyl chloride sheathing compound has the best combination of properties for use in cathodic protection. There can be no doubt that an optimum cable size exists for specific conditions of operation. The economic optimum in cable size depends on overall factors which vary with the installation, and a method and charts simplifying selection are presented.

The Effects of Interstitial Elements on the Weldability of Titanium Alloys.
By J. F. RUDY, J. B. MCANDREW, and H. SCHWARTZBART. (From *The Welding Journal, U.S.A.*, Vol. 36, No. 7, July 1957, pp. 313s–320s, 13 illustrations.)

THE purpose of the investigation described in this paper is to continue the study of the effects of the interstitial elements carbon, nitrogen, oxygen, and hydrogen on the weldability of titanium and its alloys.

Two base alloys were used as the starting point for interstitial addition, both being alpha-beta titanium alloys. Of these, the first alloy, containing 7% Al and 3% Mo, received only limited attention, because preliminary tests showed it to be, at best, marginally weldable with zero intentional interstitial additions, and the smallest addition was enough to affect its engineering usefulness seriously.

The second titanium alloy, on which most of the experimental work was done, was the commercially available 6%Al/4%V alpha-beta alloy. This alloy was found to have a much greater tolerance for interstitial elements, and a systematic study of its post-weld properties with interstitial-element additions was accomplished. The results indicated that the properties of the base alloy are not seriously impaired by as much as 0·17 to 0·20% oxygen, or up to 0·10% nitrogen. Carbon additions were lower than intended, and no alloy was produced which showed embrittlement caused by carbon alone. The highest carbon analysis obtained was 0·081%, which had no deleterious effects in the presence of subcritical oxygen and nitrogen percentages. However, two heats containing slightly over 0·10% nitrogen did indicate a slight additional embrittlement effect by carbon of the order of 0·070%.

Hydrogen up to 150 ppm does not appear to have a marked embrittling effect upon otherwise weldable alloy heats. One heat containing 0·21% oxygen showed considerable embrittlement when hydrogen was added, and another heat which had decreased ductility with 0·160% nitrogen suffered further embrittlement with hydrogen addition. Generally, however, 150 ppm of hydrogen was not deleterious to the high-loading-rate mechanical properties measured.

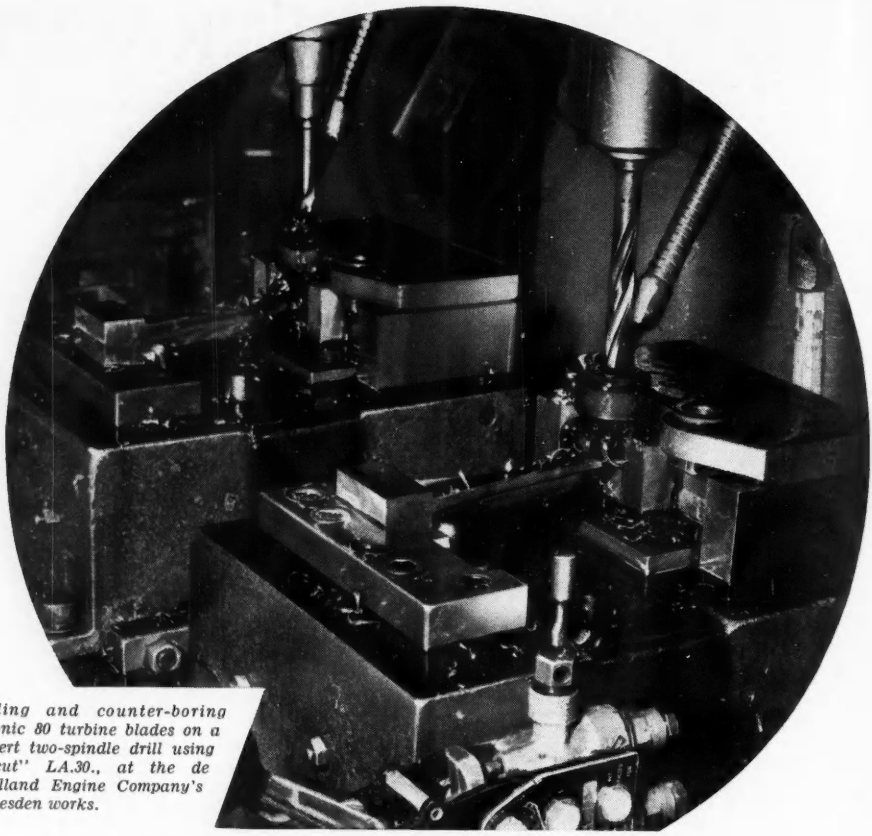
The question of whether the effect of an interstitial element adds to or subtracts from the effect of another interstitial element is shown by the data to be complex and has no simple answer. In one instance, hydrogen plus oxygen indicated an additive effect. Two other comparisons indicated an additive effect of carbon and nitrogen in combination. Another heat indicated that nitrogen plus oxygen are not additive. However, these questions should be further studied with heat analyses carefully controlled to approximately 80 to 95% of each individual element maximum. It appears that slightly subcritical amounts may be additive when combined in the same heat.

None of the six separate post-weld heat treatments performed on the interstitial additive variations of the two base alloys gave a consistent improvement in properties.

Hot Pressure Bonding.
By S. STORCHEIM. (From *Metal Progress, U.S.A.*, Vol. 72, No. 1, July 1957, pp. 97–101, 8 illustrations.)

THE hot-pressure method of bonding consists of the application of sufficient pressure to metal components at moderate temperature to form a metallurgical bond between them. This method has proved valuable in the cladding of a wide variety of metals for industrial purposes. Among its advantages is the circumstance that metallic pairs which normally form brittle and unusable intermetallics at the higher temperatures of fusion welding can be bonded with great strength and corrosion resistance, even though these same brittle alloy zones appear in the microstructure. Since the pressure applied using this technique is hydrostatic in nature, any of the strong (even if brittle) intermetallics which form do not ordinarily develop microfractures. Also, when the proper reaction precautions are taken, bonding is uniform over the entire interface—at least as evaluated by metallurgical considerations and mechanical properties. Scrap losses are extremely low, and reproducibility is extraordinarily high. Normally, losses will come from destructive testing of samples, production acceptability being of the order of 95%. Knowing the necessary bonding conditions and with proper operation of present-day equipment, high production rates of high-quality parts at a low price can be met.

The information contained in this paper largely concerns joints made between aluminium and nickel by this



Drilling and counter-boring Nimonic 80 turbine blades on a Herbert two-spindle drill using "Ilocut" LA.30., at the de Havilland Engine Company's Leavesden works.

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technique. They are typical of the results obtained with hot-pressure bonding of other systems, notably aluminium to copper, iron, or zirconium.

It is concluded that hot-pressure bonding offers a fast, cheap, reproducible, high-quality method for cladding one metal with another. It also presents some challenging problems to both theoretical and development engineers, particularly with regard to the effect of pressure during solid-state bonding. Since it has been shown that pressure can have a decided effect upon the microstructure of a binary system, the point can be raised as to whether or not present constitutional diagrams can be considered complete. Adding a third ordinate of pressure to such constitutional diagrams should prove to be an interesting and challenging problem to those investigating such areas.

The Measurement of Stresses in Rotating Discs with Holes by means of Strain Gauges.

By H. SAITÔ. (From *The Technology Reports of the Tôhoku University, Sendai, Japan*, Vol. 21, No. 2, 1957, pp. 51–61, 8 illustrations.)

A KNOWLEDGE of stress distributions in rotating circular discs is of great practical importance, and such distributions in rotating discs containing a concentric hole are well known. However, it is often necessary to drill eccentrically located circular holes for such purposes as balancing and reduction of weight, and the effects of these holes on the strength of the disc are also important. In this connection, exact mathematical solutions have been obtained for the stress distributions arising in a rotating disc of uniform thickness with a single noncentral circular hole and in a disc having a number of eccentric holes of equal radius, with the centres arranged symmetrically on a circle of arbitrary radius. However, owing to the very great difficulty of mathematical analysis of such elastic stress problems, experimental treatments have mainly been employed.

In such cases, it would appear that, although there exists a method of study in which the displacement on the disc may be measured directly, the technique of photoelasticity at present offers the best approach to solving problems of this kind. Thus, stresses in rotating discs containing concentric and eccentric holes have been investigated stroboscopically and by stress-freezing techniques. In addition, an approximate mathematical solution has been obtained for the stresses in a rotating disc with one eccentric hole, while the stress-concentration factors have been measured for a single eccentric hole and for a number of eccentric holes concentrically spaced around a central hole. Similarly, the stress-freezing method has been applied to obtain the distribution of rotating plates with holes and to examine the stress concentrations at the edges of the holes. In short, with the improvement in photoelastic methods, fairly accurate results have been obtained, though the technique still presents some difficulties.

During recent years, considerable use has been made of electric resistance strain gauges for stress determination, and these gauges are undoubtedly a valuable tool in routine investigations. Thus, for instance, they have been used for measuring the stress distributions in a rotating disc with four symmetrically located eccentric holes. However, to obtain the signal from the gauge cemented to the moving part, some form of slip-ring or sliding contact must be used, with a consequent variable contact resistance between the ring and the brushes. This variation in resistance may well be of the same order as the percentage variation in the gauge itself and, unless careful precautions are taken, reliable measurements cannot be expected.

In the investigation described in this paper, it is shown that accurate measurements of the strain in a rotating disc, together with the effects produced by eccentric holes in such discs over a considerable range of sizes, can be produced by means of a simple and inexpensive specially designed slip-ring arrangement. Basically, the installation consists of slip-rings of equal diameters (36 mm) and breadths (8 mm) mounted on a cylindrical shaft, with square brushes located in opposition to each other on both sides of the rings in the horizontal radial direction to contact each ring. The brushes are pressed against the rings by means of leaf-springs, ensuring a continuous contact pressure, and a strain indicator with a double bridge circuit is used for taking measurements. In all tests, the discs were balanced, and the values of the stress concentrations obtained were found to agree with those obtained by mathematical analysis with an error of not more than a few per cent.

Conductive Silicone Rubber

By J. H. LORENZ, M. L. DUNHAM, and C. L. BITNER. (From *Automotive Industries, U.S.A.*, Vol. 117, No. 4, August 15, 1957, pp. 100, 124, 1 illustration.)

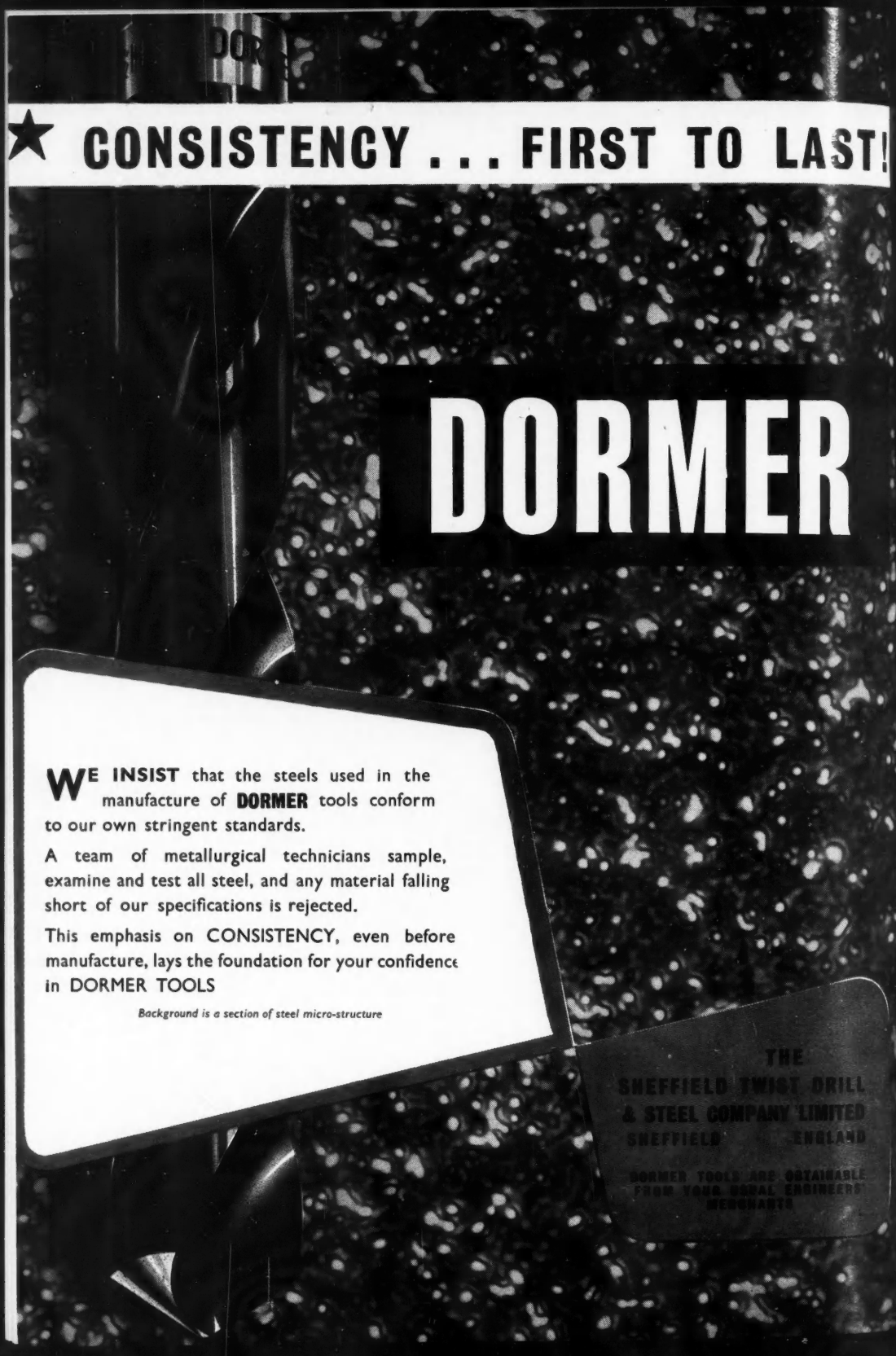
FOLLOWING the development of vinyl-containing silicone gum-stocks, new conductive silicone compositions, using carbon black as a filler, have been produced and extend the scope of conductive elastomeric materials to new fields. Thus, because of its electrical conductivity, combined with its retention of conductivity under stress and good thermal stability, it would appear that conductive silicone rubber will prove very useful in the construction of flexible heaters. In this connection, they are already finding acceptance as heater pads on aircraft cameras and as other heating units. In some applications, the non-sticking qualities of these rubbers are also of importance, e.g., in the construction of de-icing boots. They are also excellent for the dissipation of static electrical charges, and intricate designs of all types are possible, owing to their ease of processing.

The extended usefulness of these new types of silicone rubbers is based not only on the composition of the materials going into them, but also on the development of new vulcanizing methods, for it is in the process of curing that the chemical cross-linking of the polymers is accomplished. By the introduction of new catalysts, curing methods have been considerably simplified and speeded up.

The degree of conductivity in silicone rubber can be varied by the choice and amount of loading of carbon black. Extremely low resistivities are obtained over the entire range of loadings with acetylene or battery black. At higher loadings, resistivities of 2 ohm-cm and below are easily obtained in acetylene stocks. All blacks can be expected to yield conductive silicone rubber at the proper loading. In addition, those blacks designed to produce conductive compositions in other media will yield the most highly conductive silicone stocks. While any black will produce a conductive silicone elastomer, the acetylene black has the most desirable combination of properties for the practical preparation of conductive silicone rubbers. Its extremely high electrical conductivity, coupled with its compounding versatility, makes acetylene black interesting for greater consideration.

It is possible to use a mixed silica and carbon-black filler system to control the electrical conductivity or processing properties of conductive silicone-rubber stocks. It has been found that the addition of silica to a stock with an acetylene-black filler confers greater green strength and that stocks modified in this way feed more easily to an extruder, while extruded parts hold their shape better. These stocks also calender more easily, yet mould as well as unmodified stocks.

It has also been found that tensile strength and hardness increase with increasing silica content. Elongations do not fit the trend in the other physical properties. All mixer-filled rubbers have lower elongations than either the silica or the black-filled materials. This control of electrical properties seems unparalleled in the field of conductive rubbers. Also, they exhibit very little change in resistivity when elongated. Even at 200% elongation, the elastomer is still a highly conductive material. The recovery data indicate that the permanent loss in conductivity as a result of elongation is very small.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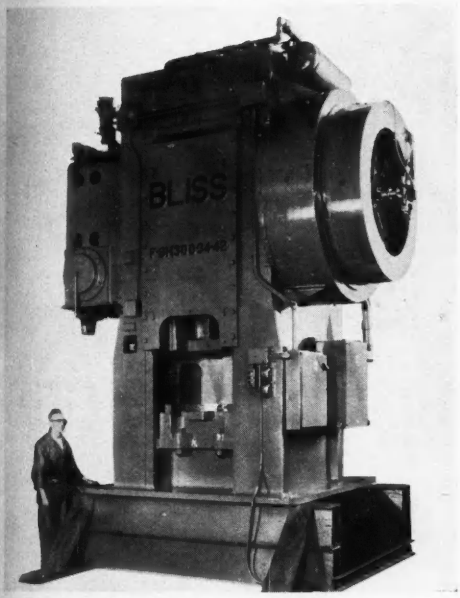
New Materials, Processes, and Equipment

HIGH-SPEED FORGING PRESSES

The recent redesign of their range of high-speed forging presses is announced by the E. W. Bliss Company, of Canton, Ohio. Thus, for instance, a tonnage limiter, which prevents accidental overloading of the press, is incorporated, automatically reducing the air pressure on the clutch as the slide approaches the bottom of the stroke, and increasing it on the return.



The brake has also been redesigned and now utilizes a double, rather than a single, clam-shell brake. This has increased the braking area and, in conjunction with a larger cylinder, has doubled the braking effect. Other features include air counterbalances, instead of the previously used " buffers "; an air-actuated wedge-type die seat; a redesigned flywheel brake; and a new gear drive for both the limit switch and lubrication pump, replacing the earlier sprocket drive. All forging presses have a solid frame.

NEW SYSTEM OF MEASUREMENT AND PRESENTATION OF FLIGHT INFORMATION

Stated to be an entirely new concept of measurement and presentation of flight information and to provide the most compact and unambiguous cockpit display known to date, the new " Flight Data " system developed by Kelvin & Hughes Ltd., of Leyton, London, E.10, presents on only four instruments information which previously required at least ten.

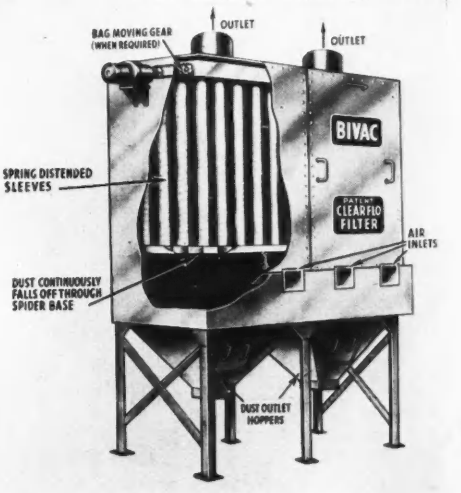
Information for the cockpit display is obtained from two central sensing and computing systems. One of these, the flight dynamic reference system, presents on two instruments information normally requiring six distinct instruments. It accepts signals from a remotely located gyro unit, from radio sources, and from a compass system, computing them and presenting to the pilot information on aircraft attitude, position in space related to a ground aid, and heading. It is also capable of supplying control signals to an automatic pilot. The second system, the aerodynamic reference system, accepts information from Pitot, static, and temperature sensers, and computes airspeed and Mach number. Altitude and rate of climb are computed and presented on a height display, which has provision for applying barometric pressure correction. True airspeed and temperature (corrected) can be fed to other equipment from the aerodynamic computer. Information may also be provided for an automatic pilot, where necessary.

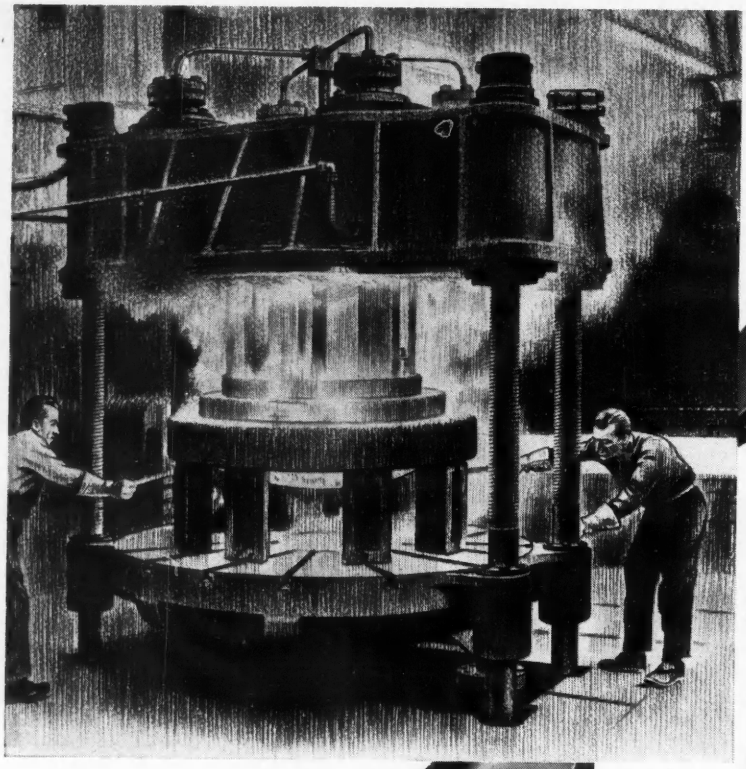
The new system, which has been produced by the combined efforts of Kelvin & Hughes Ltd., the Ministry of Supply, the Royal Aircraft Establishment, and the Institute of Aviation Medicine, and which was shown at the recent S.B.A.C. Exhibition at Farnborough, gives more accurate information and minimizes instrument lag, in addition to allowing a large amount of data to be presented in a small space.

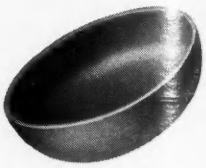
FABRIC AIR FILTER FOR HIGH DUST LOADS

The " Clear-Flo " fabric air filter, announced by the Bivac Air Co. Ltd., of Stockport, Cheshire, eliminates the disadvantages normally associated with the use of fabric air filters. Thus, for example, conventional filters connected with the chemical industry have in past years been handicapped by the fact that high dust loadings per cubic foot of air conveyed have been virtually impossible, so that cyclones or presettlers have been essential, owing to heavy build-up on the inside of the tubes or blankets of filtering cloth. Similarly, quite apart from the fact that dust retention has often been far from 100%, there is no encouragement for dust collected in the usual way on the inside of tubes of fabric to fall off, as the tube of collected dust so formed inside the fabric is a comparatively strong structure and deformation must take place before it will drop from the surface of the cloth. This undesirable feature is completely eliminated with the " Clear-Flo " filter, which is capable of coping with high dust loads of the order of 4 to 6 tons per hour at a rate of 1000 cfm. With such loadings, a total dust retention as high as 99·7%, with dust-particle size down to 0·5 micron, has been obtained.

The principle of the filter is that the dust is collected on the outside of the tubes of filter cloth, using springs







DISHED and FLANGED ENDS

Fabrication of pressure vessels may be greatly facilitated by drawing upon Harvey resources for the production of die-pressed Dished and Flanged Ends.
Capacities range from 6 in. to 9 ft. diameter. Edges are prepared for welding or riveting if desired.

STOCK SIZES : Ends pressed from Boiler Quality or Ship Quality Mild Steel up to ½ in. thickness, in most sizes up to 7 ft. diameter, are normally available from stock.

SEMI-ELLIPSOIDAL HEADS can be produced on the Rotarpress ; diameters 5 ft. to 15 ft. ; thicknesses ⅜ in. to 4 in.

For details, please ask for List No. ED 965.

Harvey

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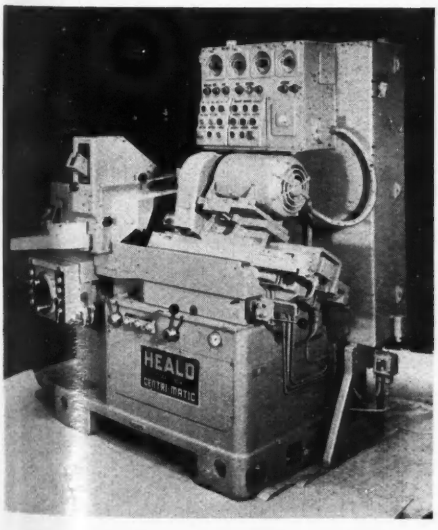
or spring-distended frames to prevent the cloth from collapsing. The dust collected then remains on the outside of the cloth and, in general, drops off under the influence of gravity. The violent bag-shaking methods sometimes required to keep the filter cloth free from dust, with the consequent high wear rate of bags, are not necessary. Where certain dusts have had to be treated or coated with fatty acids, it may sometimes be necessary to fit dust unloading gear. This unloading is achieved by moving the base holding the filter tubes a matter of ¼ in. per linear foot, the complete cycle taking one minute. It is seldom necessary to change the bags more than once per year, even when the bag unloading gear is in continuous operation. Since, with this particular design, unloading of the filter bag is largely automatic, there is a constant resistance, with consequent constant air volume—a very desirable feature with most chemical processes.

HIGH-SPEED INTERNAL GRINDING MACHINE

Capable of heavier stock removal and faster grinding cycles than have hitherto been considered possible, the "Rite-Angle Centri-Matic" internal grinding machine, developed by The Heald Machine Company, of Worcester, Massachusetts, has a wheelhead table inclined at an angle of 30 deg. to the work, and solid wheel back-up to take heavy wheel pressure, true table tracking, excellent swarf and coolant drainage, and an improved base for mounting wheelheads. Cycle times can be cut by up to 50% on work in the upper size ranges in both straight- and taper-bore grinding and in ball-track grinding on work up to 3¼ in. o.d. This increase in production speed has been achieved with no sacrifice in accuracy, precision, or surface finish of the work.

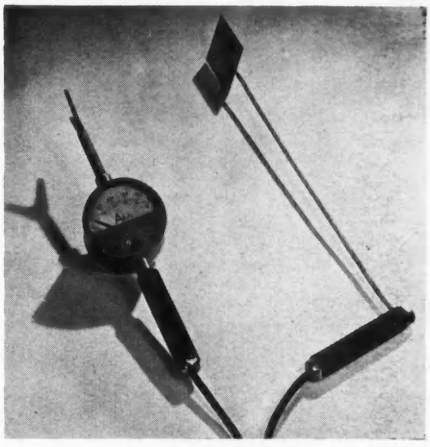
Two models are available, i.e., model 190A for straight and taper boring, and model 1901A for ball-track grinding. Both are fully automatic machines for small to medium work requiring precision internal size and finish, such as anti-friction bearings, retainer rings, gear blanks, refrigerator-compressor rolls, bushings, and similar parts. In operation, work is located and rotated on its own periphery against hard shoes and clamped against a rotating backing plate. This "Centri-Matic" work-holding method maintains the advantages of centreless grinding, while tending to bridge any waves present in the outside diameter, thus producing perfect concentricity between the ground bore and outside diameter.

A feature of the new machine lies in combining the strength and rigidity of box-type ways with the accuracy of alignment of Vee-ways. Thrust forces against the wheelhead and table in heavy grinding are against the lower side of the gib or into a horizontal Vee-way. The lower way is simply a flat guide to keep the table straight. The inclined table construction also allows clearance for various diamond-dressing units and a simple adjustment for wheelhead height. Other design and operating features include operation with high-frequency or belt-driven wheelheads, infinitely variable hydraulic cycles, efficient swarf and coolant disposal, automatic feed control with a self-adjusting diamond, and solid plug or air sizing for straight or taper bores.



PORTABLE CURRENT-DENSITY INDICATOR

The latest addition to the range of instruments produced by The English Electric Co. Ltd., of Stafford, is a portable current-density indicator for use in the electroplating industry. By giving a direct reading in amperes per square foot, it enables the current density in the electrolyte at any point of any number of loaded electroplating vats to be checked rapidly and their operating currents to be adjusted for maximum plating efficiency and consistency of quality.



The apparatus consists of a robust moving-coil ammeter connected in series with a plate electrode of known surface area. The electrode is immersed in the electrolyte between the component to be plated and the anode and, when contact is made with the work-bar through a forked spike on the ammeter case, a direct indication of current density in the vat at that point is given on the ammeter dial. Two electrodes are supplied, one of stainless steel for use in stannate tin, zinc, and cadmium vats, where current density does not exceed 50 A/sq ft, and a second special glass-backed electrode for use in chromium and bright-nickel vats, where current density is up to 250 A/sq ft. Selection of the correct electrode enables readings with an accuracy of ± 5% to be readily obtained.

VERTICAL MILLING MACHINE WITH FULL-WIDTH KNEE

A new medium-duty vertical milling machine, developed by the George Gorton Machine Company, of Racine, Wisconsin, has a full-width knee securely mounted on the column by a square lock bearing of generous width, the knee itself being 24½ in. wide, i.e., almost as wide as the saddle is long. This feature ensures maximum rigidity under heavy cutting loads by providing a support to the workpiece closely approaching that of a bed-type machine. A narrow centre-guide bearing is provided on both the column and knee to

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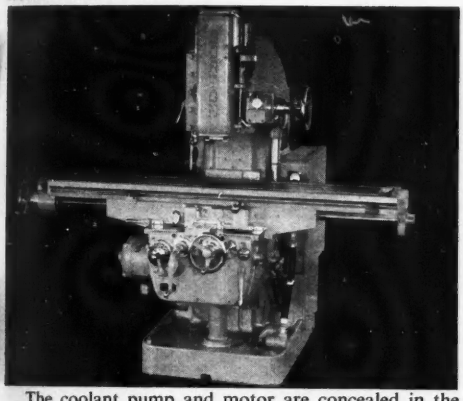
SHERBORNE STREET, BIRMINGHAM 16

furnish a positive guard against twisting of the knee and cocking of the saddle.

The spindle of the new machine, designated the "3-34", is powered by its own motor via a simplified and highly efficient gear-train. A separate motor provides power for longitudinal, cross, and vertical feeds, as well as for vertical feed of the spindle. The saddle design includes an enclosed coolant-return channel, which in no way reduces the bearing area, while backlash adjustment of the table screw is provided at the front of the saddle for greater convenience. The knee feed-box, feed-distribution assembly, and spindle-speed box are of unit construction, with consequent advantages regarding adjustment and maintenance. Dual overload protection is provided for all feeds, mechanical interruption taking place if the feeds are too heavy, and an overload current relay instantly stopping all feeds if the spindle is overloaded beyond the rated capacity of the machine. In addition, a standard circuit-breaker is located in the control box.



The coolant pump and motor are concealed in the column base below the main control panel and are easily accessible through a hinged door. An interesting feature is the use of a removable coolant pan, facilitating cleaning and, with extra pans, permitting rapid interchange of coolant.

PICTURE TRANSMISSION SYSTEM

A new picture transmission system, designated "Deccafax", has been introduced by Decca Radar Limited, of London, S.W.9, and is capable of transmitting television-type pictures and sound between points interconnected by coaxial cable at distances up to 2000 yards. The system incorporates a master unit (illustrated) which can be used both as a receiver or a transmitter. It can therefore be connected to other master units for two-way speech/vision intercommunication in offices, stores, factories, etc., or to modified standard television sets for one-way announcements, etc.

The most interesting feature of the Deccafax system is its versatility. The transmitted picture or message can take many different forms, ranging from complete 35-mm motion-picture films, strip-films, and slides to simple transparencies of diagrams or pro-formas. Equipment to move strip-films and slides automatically is also available. Furthermore, the possibility of using standard television sets as receivers opens up a number of useful applications. Thus, for example, announcements can be routed from a single master unit to all or any desired number of television receivers at an airport terminal, these receivers being also used to receive normal television programmes for entertainment purposes.

An important application of the Deccafax system is in meeting the requirement of information collation and filtering at centres where complicated visual displays are necessary, such as at air-traffic control centres and defence

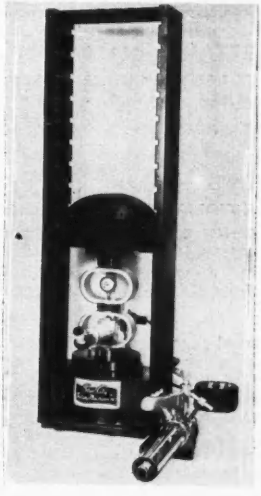
operations rooms. A number of remote master units can be interconnected to feed different types of information to a central receiver for enlargement on a viewing screen. Control can be exercised over the various inputs, so that the main display shows only the specific information necessary at any one time. Filtering in this way makes it far easier for viewers to appreciate the significance of the events which concern them.

Other interesting uses of the Deccafax system include the reversal of photographic negatives and their display as positives, the superimposing of several pictures on a single viewing screen, and the ability to give private cinema shows without using a noisy projector in the same room and without the necessity for total darkness.

PORTABLE COMPRESSION TESTER

A compact and portable hydraulically operated machine for quick and accurate compression testing, combining simple hand-pump operation with ease of adjustment in the vertical direction, is announced by Steel City Testing Machines, Inc., of Detroit, Michigan. The overall weight of the new tester, designated model TP-121, is about 170 lb, and convenient carrying handles are provided, while the hand-pump folds into a vertical position for greater compactness and portability. The tester was originally designed for use in the calibration of proving rings and other load-measuring devices, a load gauge being unnecessary in such applications. For normal compression-testing purposes, however, a suitable gauge, mounted at the rear of the pump, is available.

Despite its portability, the machine, which has a capacity of 150,000 lb, is equally suitable for stationary use in laboratories for conventional compression-testing purposes, and many different types of work can be catered for. By removing eight screws, the position of the upper head can easily be changed, sliding it out of one pair of slots and into another, as required. The width between the uprights is 11 in., and any vertical dimension between 9½ and 32 in. is available. The upper anvil is spherically seated, to assure perfect alignment during testing operations. The hand-operated pump providing the compressive force incorporates its own oil reservoir.



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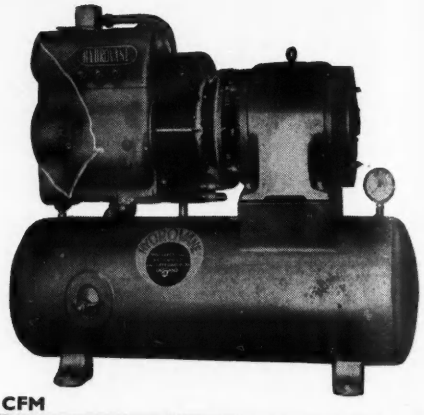
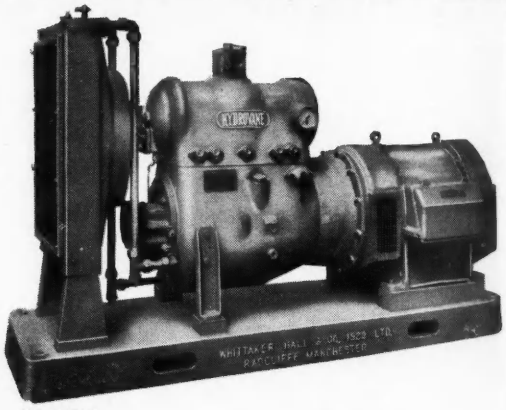
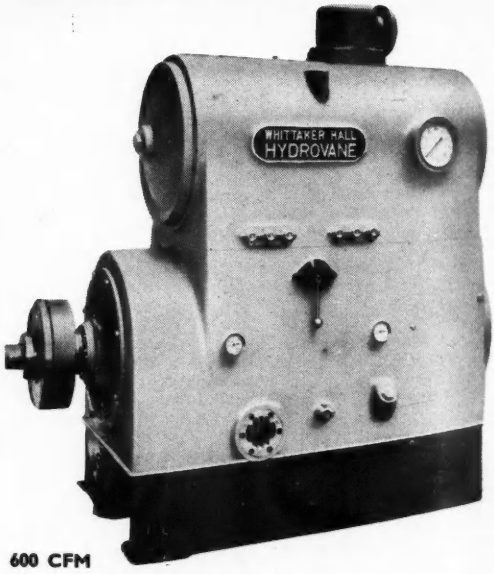


60 CFM



210 CFM

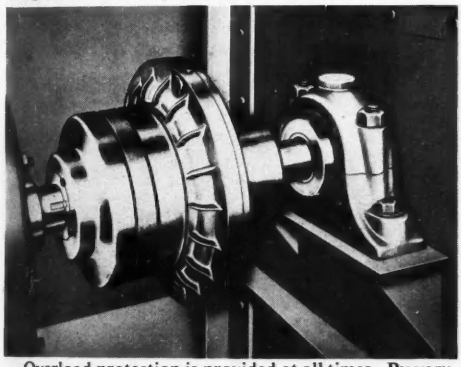


600 CFM

DRY FLUID DRIVE AND COUPLING

A new dry fluid drive and coupling, the " Flexidyne ", developed by the Dodge Manufacturing Corporation, of Mishawaka, Indiana, not only provides protection against overloads in various industrial applications, but is stated to ensure positive speed control, dependable operation, and a saving of at least 4% in power over any other type of fluid drive.

The dry fluid in the new drive is heat-treated steel shot, a measured amount of which, called the flow charge, is contained in the housing, which is keyed to the motor shaft. When the motor is started, centrifugal force throws the flow charge to the perimeter of the housing, packing it between the housing and the rotor transmitting power to the load. After a brief starting period with slip between the rotor and housing, the two units become locked together and achieve full-load speed, operating thereafter without slip and at 100% efficiency. In this way, the motor is permitted to pick up the load gradually. As a result, smaller motors can be used, smoother starts are obtained, and power factor is improved. Furthermore, starting torque can be varied to suit various load requirements by altering the flow charge, i.e., the higher the flow charge, the more torque can be transmitted.



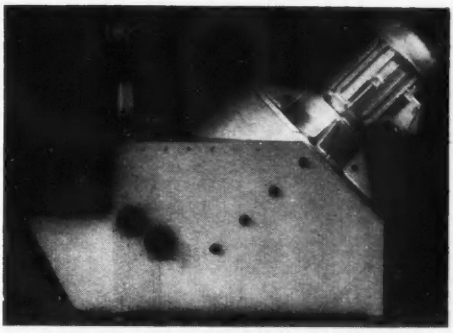
Overload protection is provided at all times. By varying the flow charge, slip at any desired load can be obtained. A thermal switch can, if desired, be installed, to cut out the electrical circuit if an overload condition persists. In general, reversing loads are also easily handled. During both starting and overload periods, current consumption is at a minimum (usually less than twice the nameplate amperage. With the standard " Flexidyne " setting, the motor never runs at less than 90% synchronous speed, even when the load is stalled.

The new drive is stated to be particularly suitable for use with internal combustion engines. While it always provides a smooth start, it can be set to lock in either at low speed to allow operation without slip over the complete range of higher speeds, or at high speed to provide minimum drag torque and ideal overload protection.

CENTRIFUGE FOR CLARIFYING GRINDING COOLANTS

The " Turbomatic " centrifuge, recently developed by the Alfa-Laval Company Ltd., of Brentford, Middlesex, for the clarification of grinding coolants has been specifically designed to feed really clean coolant to grinding or honing machines, with a continuous efficiency of 99·98% at throughput rates of up to 2200 gph of either oil or aqueous coolant.

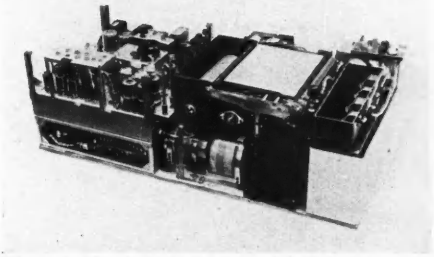
The machine has an inclined large-capacity centrifugal bowl running at 1450 rpm, and is fitted with a large disc pack to give high-efficiency separation. The extracted sludge builds up on the bowl wall, from which it is thrown down into the sludge trough forming the base of the unit, when required. This ejection is achieved by the rapid " braking " of the bowl through the use of a current-reversing switch. The whole ejection operation takes less than one minute. The sludge capacity of the bowl is 4 gal and only under exceptional conditions is ejection required more than twice a day ; eventual removal of sludge from the trough is about once a week. The machine, which is of extremely robust and compact construction, requires no lubrication and is silent in operation. Furthermore, tests have shown that the centrifugal action has no detrimental effect on any coolants used.



RADAR STRIP RECORDER FOR INSTANTANEOUS AERIAL MAPPING

Initially designed for use with an airborne radar system, but also useful as a ground recorder of radar or telemeter information relayed from flying radar sets, the new radar strip recorder developed by the Hycon Mfg. Company, of Pasadena, Cal., is capable of producing a photographic radar map within twenty seconds on a slowly moving strip of film. The film transparency passes over a viewing screen, approximately 9 × 12 in. in size, and pictures the ground immediately behind the aircraft. The film picture does not change, but rather the long strip of film is slowly wound from one spool to another at a speed which can be controlled to correspond with the speed of the aircraft. As a result, a permanent film record of the flight path of the aircraft is obtained, combining the advantages of radar and photography.

One of the key elements in the system, and associated with the strip recorder, is a rapid film processer, specially designed by Hycon. Basically, this device is a high-speed developing machine which uses a single-bath solution operating at 130°F, and which produces a completely developed film, ready to view in strong light, in 10 sec. The transparency produced can then be viewed directly on the translucent lighted screen. The complete recorder and processer (without case) is illustrated.



The recorder incorporates special electronic circuits which automatically correct for distortions caused by the altitude of the aircraft. In addition, manual controls permit adjustment for wind drift up to ±12 deg., so that the radar map obtained from the machine can be compared or checked directly with a topographical map or aerial photographs of the region below.

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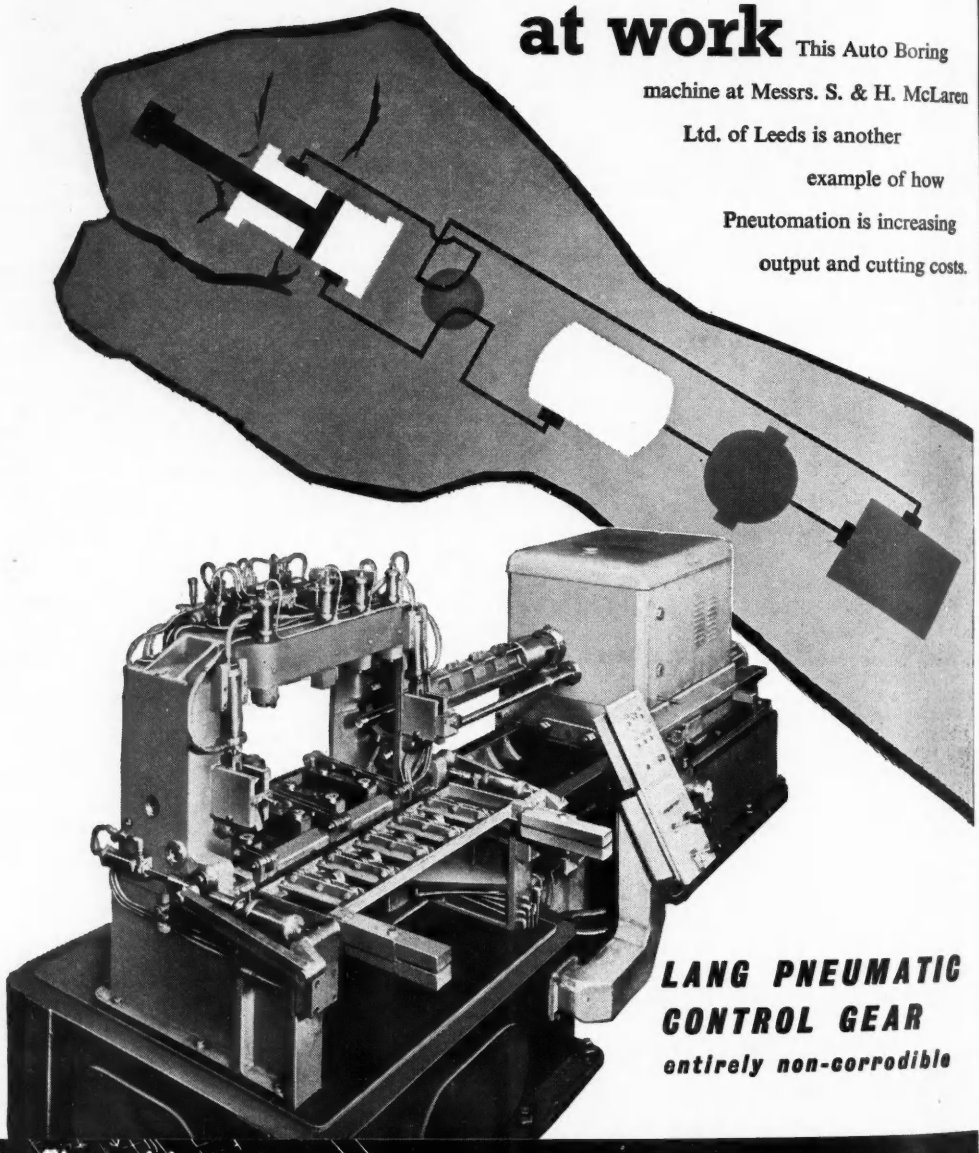

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NEWS OF THE MONTH

PERSONAL

Mr. A. E. Ackerman has been appointed sales director of Harold Andrews Sheepbridge Ltd. **Mr. B. C. Goodwin** retains his position as sales manager. **Mr. J. J. Carroll** has joined Sheepbridge Stokes Ltd. as manager of the single cast ring foundry.

Mr. James Annandale, D.F.C., A.M.I.E.E., sales manager of Partridge, Wilson & Co. Ltd., Davenset Electrical Works, Evington Valley Road, Leicester, who has been with the Company for over 25 years, has been elected to the Board.

Mr. T. H. Arnold, M.B.E., F.I.M., has been appointed research controller and local director of Hadfields Ltd., East Hecla Works, Sheffield 9. He has also been appointed to the Board of Hadfields Steels Ltd. and Hadfields Forgings Ltd. **Mr. L. G. Finch, B.Met., Ph.D.,** has been appointed deputy research controller. **Mr. D. R. Eastwood, M.I.Mech., M.I.E.E.,** deputy chief engineer, has been appointed local director of Hadfields Ltd. and director of Hadfields Foundry & Engineering Co. Ltd. **Mr. S. Leetch, M.C.,** works controller, has retired from industrial activities.

Mr. H. E. Cornish, O.B.E., M.C., B.Sc.(Eng.), A.C.G.I., M.I.E.E., former Postmaster General of Sarawak, has been appointed general manager of British Telecommunications Research Ltd., Taplow, Bucks, the research establishment jointly sponsored by Automatic Telephone & Electric Co. Ltd. and British Insulated Callender's Cables Ltd.

Lt.-Col. C. P. Dawnay, C.B.E., M.V.O., has been elected a director of Electrical & Musical Industries Ltd., Hayes, Middlesex.

Sir Roy Dobson, C.B.E., Hon.F.R.Ae.S., J.P., a director of the Hawker Siddeley Group Ltd., has been elected deputy chairman of The Brush Group Ltd., 32 Duke Street, London, S.W.1.

Mr. Bernard Dyer has been appointed general manager of the Planning Division, and **Mr. Gordon Smith** deputy general manager of the Manufacturing Division, of F. Perkins Ltd., Peterborough.

Mr. Douglas Hall, A.Met., F.I.M., has joined Low Moor Alloy Steelworks Ltd., Low Moor, Bradford, and Yorkshire Rolling Mills Ltd., as general works manager.

Mr. K. E. Harris, technical director of Cossor Radar & Electronics Ltd., Cossor House, Highbury Grove, London, N.5, has been awarded the 1956 Brabazon premium of The British Institution of Radio Engineers for the most outstanding contribution to radio and electronic devices for aircraft safety.

Mr. Norman Harvey, M.Sc., has been appointed development manager of the Aston Chain & Hook Co. Ltd., Erdington, Birmingham.

Mr. V. H. F. Hopkins, M.I.Mech.E., has been appointed manager of engineering, Diesel Engine Division, of The English Electric Co. Ltd., Marconi House, Strand, London, W.C.2, directly responsible to the general manager, **Mr. A. C. Wilkin.**

Mr. Hector McNeil, B.E., M.I.Mech.E., M.I.E.E., deputy managing director of Babcock & Wilcox Ltd., 209 Euston Road, London, N.W.1, unanimously elected president of the Institute of Fuel, will take the chair as president on the occasion of the Institute's Annual Dinner at Grosvenor House, London, on Tuesday, October 22.

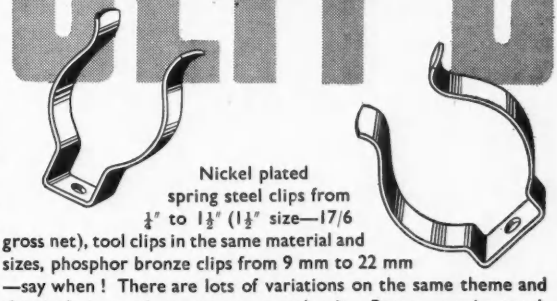
Mr. W. E. Ogden, M.C., F.C.A., and **Mr. W. W. Dolton,** chairman and managing director respectively of the Delta Metal Co. Ltd., have been elected to the Board of James Booth & Co. Ltd. and its subsidiary company, John Wilkes Sons and Mapplebeck Ltd., which have recently been acquired by the Delta Metal Co. Ltd.

Mr. A. J. Peech has been appointed general managing director of The United Steel Companies Ltd., 17 Westbourne Road, Sheffield 10, in succession to the late **Mr. Gerald Steel.** Mr. Peech has been deputy general managing director of the Company since 1950. He is a member of the executive committee of the British Iron and Steel Federation and a director of British Iron and Steel Corporation Ltd. and B.I.S.C. (Ore) Ltd. His board appointments include Barrow Steel Works Ltd., The Butterley Co. Ltd., McCall & Co. Ltd., Steetley Co. Ltd., and Tinsley Wire Industries Ltd.

Mr. J. R. Rait, D.Sc., Ph.D., A.R.T.C., research controller of Hadfields Ltd., has taken up a new appointment as joint managing director of Briton Ferry Steel Co. Ltd., a subsidiary of Duport Ltd.

CLIPS

SPRING STEEL
PHOSPHOR BRONZE



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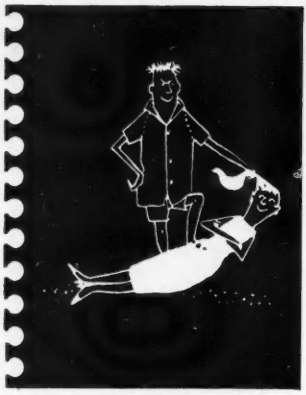

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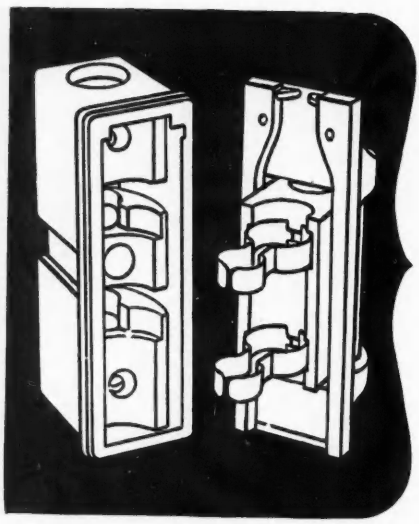

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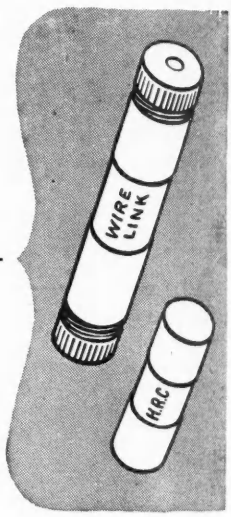

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Mr. E. D. Robinson has been appointed Manchester area sales manager of Northern Aluminium Co. Ltd., Bush House, Aldwych, London, W.C.2, to succeed **Mr. D. A. Corbett-Thompson,** who is now export sales manager. **Mr. M. Bridgewater** has been appointed manager of the Sales Development Division, Banbury, to succeed **Mr. E. D. Iliff,** who is now sales manager in charge of Sales Development, Advertising and Publicity.

Commander Michael B. St. John, D.S.C., R.N. (Retd.), has been appointed managing director of Liquid Systems Ltd., Norwich Union House, Wellesley Road, Croydon.

Mr. J. C. L. Southam has been appointed deputy commercial manager (Diesel) of D. Napier & Son Ltd., The Vale, London, W.3, responsible for the direction and supervision of the Deltic and turbo-blower sales department.

Mr. A. M. Taylor, M.A., F.C.I.S., secretary and commercial manager of Foster Transformers Ltd., S. Wimbledon, London, S.W.19, has been elected a director of the Company.

Mr. J. Taylor has been appointed sales manager, hot strip rolling mills, **Mr. I. Mulhearn,** sales manager, cold strip rolling mills, and **Mr. P. Sherwell,** manager, central sales office of Steel, Peech and Tozer, a branch of The United Steel Companies Ltd., 17 Westbourne Road, Sheffield 10.

Mr. Lester A. Wells, former president and general manager of Engineering & Research Corporation, Riverdale, Md., U.S.A., has been appointed executive vice-president of Thieblot Aircraft Company, a division of Vitro Corporation of America, 261 Madison Avenue, New York 16, N.Y., who have production facilities at Martinsburg, W.Va., and an engineering and research office in Bethesda, Md.

MR. GERALD STEEL, C.B.E.

With the deepest regret we have to announce that Mr. Gerald Steel, C.B.E., general managing director of The United Steel Companies Limited, and president-elect of the British Iron and Steel Federation for 1957, died at his Wimbledon home on September 13. He was 63.

Mr. Steel had been actively associated with the iron and steel industry since 1919, when he joined the Steel, Peech and Tozer branch of the then newly-formed United Steel group. In 1928 he went to India to form The United Steel Companies (India) Ltd., being appointed managing director of the new company. He returned to this country in 1932 to become a director and general manager of Samuel Fox and Co. He was appointed a director of United Steel in 1941 and then successively assistant managing director, joint managing director, managing director, and finally general managing director in 1954.

Educated at Charterhouse and Oriel College, Oxford, Mr. Steel served throughout the first world war with the Royal Fusiliers and the King's African Rifles in East Africa.

As president-elect of the British Iron and Steel Federation, he was a member of its council and executive committee and also served on the British Steel Producers' Conference. He was chairman of the Central Council of Iron and Steel Employers Associations and a vice-president of the Iron and Steel Institute.

MR. JAMES WILLIAM KENDALL

It is with the deepest regret that we have to announce the death of Mr. James William Kendall, head of the nuclear engineering development department of John Thompson Limited. He was one of Britain's leading authorities on the design of gas-cooled graphite-moderated reactors.

Mr. Kendall joined John Thompson in a senior advisory capacity, from the U.K.A.E.A. (Industrial Group) in June 1956. With the U.K.A.E.A. he had been engineer in charge of design and construction of projects, including Harwell B.E.P.O., the Windscale production piles, and the Dounreay fast-breeder reactor.

Mr. Kendall was one of the original twelve of the Risley Atomic Group, Ministry of Supply, which later became the Industrial Group of U.K.A.E.A. During the war he was assistant director, Filling Factories, working for Sir Christopher Hinton.

BUSINESS NOTES

American Nuclear Society Winter Meeting. Recent nuclear developments, ranging from solid-state theory to reactor evaluation, add up to a full programme for the Second Winter Meeting of the American Nuclear Society, to be held at the Henry Hudson Hotel, New York City, October 28-30.

Concurrent with the ANS meeting will be the Atomic Industrial Forum's fourth annual conference at the Plaza Hotel, the 1957 Trade Fair of the Atomic Industry in the New York Coliseum, and the annual meeting of the Professional Group on Nuclear Science of the Institute of Radio Engineers. In addition, ANS, the Atomic Industrial Forum, and the Atomic Energy Commission will sponsor a special conference on reactor safety at the Coliseum, October 31.

The four-day ANS technical programme will consist of 24 sessions, at which more than two-hundred 15-minute papers will be presented. Monday, October 28, will be high-lighted by a series of nine papers on the Army Package Power Reactor, while on Tuesday and Wednesday 10-paper sessions will be held on Reactor Concepts and Evaluations. Other sessions will cover subjects including chemistry and fuel processing; reactor theory, physics, engineering, and kinetics; reactor safety and health physics ; fuel element metallurgy ; and shielding studies.

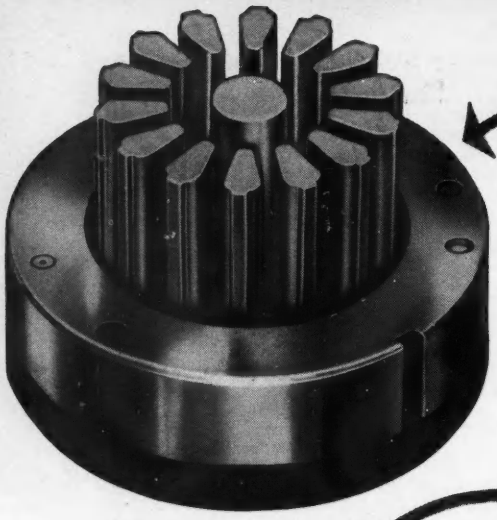
At a special luncheon on Tuesday, October 29, ANS will have as guest speaker Dr. Henry D. Smyth, formerly of the AEC and now a member of the Princeton Matterhorn Project group which is investigating thermo-nuclear reactions. The evening of the 29th will feature a joint ANS-AIF reception and banquet at the Waldorf Astoria Hotel. Guest speakers will be two internationally known leaders in the field of nucleonics, Sir Edwin Plowden, Chairman of the United Kingdom Atomic Energy Authority, and Admiral Lewis L. Strauss, Chairman of the U.S. Atomic Energy Commission.

Other events of interest include a student programme entitled " Nuclear Industry and Your Future ", sponsored by the New York Metropolitan Section of ANS, and trips to Sylvania-Corning Bayside Laboratories, Esso Research Center, and Brookhaven National Laboratory.

The Brush Group Limited has formed a subsidiary, National Free Piston Power Ltd., for marketing at home and overseas free-piston gasifiers, manufactured by the National Gas and Oil Engine Co. Ltd., under Pescara/SEME/Muntz licence.

Mr. Donald Robson, formerly of Alan Muntz, has been appointed executive director of the new company, in which capacity he will be responsible to Mr. B. R. Cant, general manager of the National Gas and Oil Engine Company. Other directors of the company are Mr. Ian T. Morrow Chairman (managing director of the Brush Group), Mr. C. F. Barnard, and Mr. F. Warhurst.

Ateliers de Constructions Electriques de Charleroi (ACEC) and **S. A. Cockerill-Ougrée** have signed a licence agreement with the Westinghouse Electric International Company, which will permit them to manufacture and sell all the non-military types of reactors developed by the American company.



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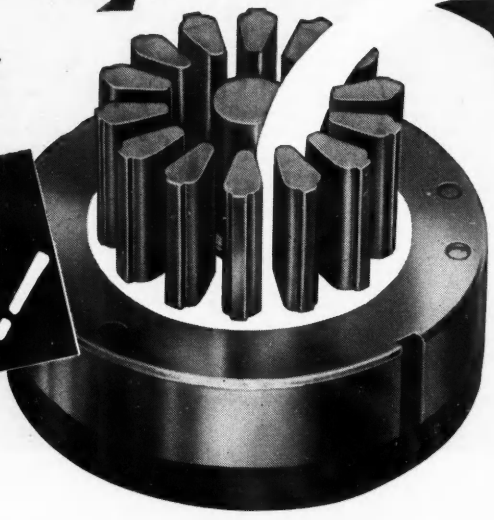

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Valid for a period of fifteen years, the agreement grants to the licensees:

–An exclusive right to manufacture in Belgium all types of reactors developed by Westinghouse for land, marine, or airborne purposes.

–A right to sell in all parts of the world, except the United States and Canada, the types of nuclear power stations and equipment designed by Westinghouse.

–All specifications and "know-how" for manufacturing processes and test procedures.

–The right, not only to send staff on information missions to Westinghouse, but also to delegate to the latter a number of engineers for a period of 3 years, during which time they will work with their American colleagues on the design and manufacturing work in progress.

It should be remarked that the agreement leaves ACEC and Cockerill-Ougrée free to take part in the manufacture of types of reactors other than those designed by Westinghouse.

The Allis-Chalmers Manufacturing Company, Milwaukee, Wis., U.S.A., announce the formation of Allis-Chalmers International as a major operating division of the Company.

Mr. P. F. Bauer, general manager, Industrial Equipment Division has been named managing director of the new division. The new division will be responsible for manufacturing, engineering, and sales operations and activities outside the United States and Canada. Manufacturing operations include plants in Essendine, England, which produce wheel tractors, harvesters, and vibrating screens, and in Newcastle, Australia, where motor graders are now manufactured.

Materials Handling Equipment (Great Britain) Ltd., sole concessionnaires for the IRION side operating fork-lift carriers and specialists in mechanical handling equipment of all types, announce their removal to larger premises at 40a, Dover Street, London W.1.

BTR Industries Ltd. (formerly British Tyre & Rubber Co. Ltd.), announces that they have opened a new branch office and warehouse at Marshall House, Marshall Street, Birmingham 1 (Tel.: Midland 4602), to extend their service to industry in the Midland area. The new office will be managed by Mr. D. H. Turner.

Wickman Limited announce their recent appointment as sole agents in the United Kingdom for the range of microfinishing machines manufactured by Maschinenfabrik Ernst Thielenhaus, Wuppertal-Barmen, Germany.

Haveg Industries, Inc., 900 Greenbank Road, Wilmington 8, Delaware, U.S.A., have acquired, as a wholly owned subsidiary, the Reinhold Engineering and Plastics Co., Inc., Norwalk, California. Dr. John H. Lux is President of Haveg.

The Goodyear Tyre & Rubber Co. Ltd. have a new Scottish factory at Garscadden, Glasgow, opened on September 26 by Lord Strathclyde, Minister of State for Scotland. He described the occasion as a significant major development in the tyre-manufacturing industry. Mr. E. J. Thomas, president and chief executive of the Goodyear Tyre and Rubber Company, said that he looks forward to the continued growth of the rubber industry. Goodyear is using one-seventh of the world's rubber. Its new synthetic plant was designed to ensure that if natural rubber was excluded it would still have ample supplies of synthetic rubber at a reasonable price. The Scottish factory is the 61st Goodyear production unit.

Associated Commercial Vehicles Ltd., 50 Page Street, London, S.W.1, will set up their own assembly plant and service organization at Umtali, for the Federation of Rhodesia and Nyasaland. A new company, A.C.V. Central Africa (Pvt.) Ltd. will be formed, with Mr. Robert E. W. Holmes as director and general manager.

The Plessey Company Limited announce the formation of a subsidiary company, Rosite Limited, which will produce at its Swindon factory a wide range of cold-moulded plastics for use in the electrical industry. As the result of an agreement, these plastics will be similar to those developed by the Rostone Corporation, of Lafayette, Ind., U.S.A.

BRITISH STANDARDS

(*Copies of British Standards may be obtained from the British Standards Institution, 2 Park Street, London, W.1*)

Cast-iron surface plates and granite surface plates. B.S. 817: 1957. Although issued as a revision, this British Standard incorporates a number of completely new features and embodies a new approach to the specification of high-grade surface plates, which should be of particular interest to those concerned with precision measurement. The increasing accuracy with which parts can now be manufactured in turn demands even more accurate measuring tools, and this is particularly true of basic inspection equipment such as surface plates. Furthermore, the fact that finer tolerances are now applied to much larger and heavier workpieces than formerly gives added emphasis to the importance of rigidity in surface plates. The specification for Grade A plates is accordingly based on this criterion, which is also applied to granite plates, requirements for which have now been included in the standard. A method of checking the deflection of surface plates under load is described in detail. Among obvious advantages to the user is the fact that he now has a guide as to how far a surface plate can be loaded before its flatness is affected by lack of rigidity. Tolerances on flatness have now been halved for Grade A cast-iron plates and similar tolerances are specified for granite plates. The appendices contain recommendations regarding dimensions and material and useful information on methods of test which afford practical help in achieving the desired results. Price 5*s*.

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General-purpose Acme screw threads, B.S. 1104 : 1957. Acme screw threads, introduced more than 60 years ago, are now used extensively for a variety of purposes. Since the publication of the 1943 edition of " General-purpose Acme screw threads " the need had been established for a range of threads suitable for different classes of work. Hence, the issue of this revised edition, which was prepared under the authority of B.S.I.'s Mechanical Engineering Industry Standards Committee. It replaces the 1943 edition, which was withdrawn when the American Standards Association began the revision of their standard, on which B.S. 1104 : 1943 was based. The revision is in accordance with its American counterpart (ASA B1.5:1952) as regards diameters, pitches, and limits and tolerances for the three classes of thread designated "2G", "3G" and "4G". An additional class—"5G"—has, however, been provided in the British Standard. A thorough review of British industrial usage has compelled a departure from the U.S. Standard Series of diameter/pitch combination in respect of $\frac{3}{8}$ in., $\frac{7}{16}$ in., 1 in., $1\frac{1}{8}$ in., and $1\frac{1}{4}$ in. diameters. Tables of effective diameter tolerances for an extended range of diameter/pitch combinations are provided in the standard, and from these and other related tables the limiting dimensions for any special diameter/pitch combination of single or multi-start Acme form thread can be calculated. The general-purpose threads specified in the standard have clearance on diameters for free lateral movement to accommodate possible errors in alignment of the axis of the fixed nut and that of the screw which engages with it. They are not intended for applications where centralizing is necessary; such threads may form the subject of a separate standard. The standard recommends that the threads be gauged according to British principles and practice. Price 7*s*. 6*d*.

Solid-drawn copper-alloy tubes for heat-exchange equipment in the petroleum industry. B.S. 1464 : 1957. This revised edition of B.S. 1464 specifies requirements for the following alloys (the 1948 edition specified only the first two): Aluminium brass—CZ 110, Admiralty brass—CZ 111, 7% aluminium bronze (copper-aluminium)—CA 102, 70/30 brass—CZ 105, 70/30 copper-nickel—CN 107. The two sections of the publication ("General Clauses" and "Specific Clauses" respectively) are supplemented by an appendix which contains eight half-tone photographs illustrative of grain size and reproduced by courtesy of the American Society for Testing Materials. Price 4*s*.

Wooden pattern equipment for foundries. B.S. 467 : 1957. The 1952 edition of this standard prescribed only a method of colouring and marking wooden patterns used for ferrous and non-ferrous castings; the new edition, now published at the request of the National Society of Master Pattern Makers, includes the same information and coloured diagram, together with a set of provisions dealing generally with the construction of wooden patterns. The standard includes clauses specifying the types and conditions of timber to be used and the construction of wooden pattern equipment. Other clauses deal with the provision of information by the pattern maker to the foundry. Price 5*s*.

Motor starters and controllers. B.S. 587 : 1957. B.S. 587 was first issued in 1937, and this new edition is its third revision. The standard now applies to a wide range of different types of hand-operated and automatic starters and controllers as used with a.c. motors of rated voltage up to 11 kV and d.c. motors up to 650 V. Requirements for resistors and auto-transformers and similar equipment associated with motor control gear are also included. Standard ratings are specified on the basis of the main mechanical and electrical duties for which control gear is required, and standard sizes of starters and controllers are recognized in terms of motor horse-power. Full details are included of the standard duty ratings for resistors for use in motor control gear which have been generally recognized in industrial practice and in previous editions of B.S. 587. The design and constructional requirements deal with many aspects of control gear, including, for example, details relating to mounting, provision for earthing and earth continuity, preferred standards for push-buttons and indicating lamps, undervoltage and overload devices, overcurrent and breaking capacities, etc. Limits of temperature rise for various types of contacts, conductors, coils, auto-transformer windings, and resistors are specified. The type tests include mains-current heating tests, voltage tests on shunt coils, and electrical performance and mechanical endurance tests. The routine tests comprise a high-voltage insulation test and tests on resistors, auto-transformers, voltage coils, and overload devices.

Seven appendices provide additional information on temperature measurement, clearance and creepage distances, and resistor ratings, together with a graphical presentation of the maximum starting times for various types of motor starters. "Information to be supplied with an enquiry or order" forms the subject of one appendix. Another contains a summary for the special requirements for switching starters for a.c. motors of 1 to 25 hp. The standard was prepared under the authority of the Electrical Industry Standards Committee. Price 8*s*.

Methods of test for air filters used in air-conditioning and general ventilation. B.S. 2831 : 1957. Prepared under the authority of B.S.I.'s Mechanical Engineering Industry Standards Committee, this new British Standard applies to methods of testing air filters. It does not specify standards of performance. Section Two of the standard relates to the "methylene-blue efficiency test". The methylene-blue dust used contains only fine particles. Because of this, the test is a severe one, and a filter exposed to normal atmospheric impurities would be expected to show higher efficiencies than those indicated by the test results. Nevertheless, the test provides a fair comparison of the relative efficiencies of different filters when used under similar atmospheric conditions. Among the requirements in this section of the standard are those for the test rig, calculation of results, and apparatus for the production of test dust. The section is fully illustrated, Section Three deals with a test for "dust-holding capacity and gravimetric efficiency". The foreword to the standard points out that atmospheric pollution differs from the standard methylene-blue dust cloud in that it may contain some coarse particles in addition to the fine ones ; this small proportion of larger particles is believed to be mainly responsible for the clogging of a filter, with consequent increase of resistance and termination of its useful life. It is because the life of a filter may be as important as its efficiency that the methylene-blue test is supplemented by a test for dust-holding capacity which employs two grades of coarse dust. Among the requirements in this section of the standard are those for the test rig, ancillary equipment, and reporting of results. The section is fully illustrated.

The Standard's four appendices include one which lays down a specification for esparto paper and another which provides a worked example of the method of calculating the value of methylene-blue efficiency.

The electrical performance of rotating electrical machinery. B.S. 2613 : 1957. When in 1955 the four principal standards for rotating electrical machines (B.S. 168, B.S. 169, B.S. 225, and B.S. 226) were revised and published jointly as B.S. 2613, it was appreciated that this was only an intermediate step pending certain developments affecting rating and temperature rise. In the latest edition the load-with-overload basis of rating has been eliminated and all machines have either con-

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tinuous ratings or short-time ratings. The other principal change from the previous edition lies in the section dealing with temperature rise, where five classes of insulation (A, B, L, F, and H) are now specified. In other sections types of enclosure are classified, preferred horse-powers and speeds are given, and the requirements for type and routine tests are specified. In general, these follow the 1955 edition, but several minor changes have been made in the interests of clarity. Price 7*s.* 6*d.*

Vegetable-tanned leather belting. B.S. 424 : 1957. This revision of B.S. 424 is the result of a review of the 1931 edition in relation to the quality of hides now available. The principal differences between this and the earlier edition are : (i) Strips must now be cut at a maximum distance from the backbone. (ii) Hides have to be rounded into butts before tanning. (iii) New requirements are specified regarding the number and position of "open" and "blind" warbles. (iv) Splices are specified on a substance basis, rather than on width. They are no longer required to be stitched, since stitching is now considered to weaken rather than to strengthen the join. Wherever possible, the chemical methods of test make reference to the British Standard for the sampling and analysis of vegetable-tanned and chrome-tanned leather.

Classified Advertisements

The rate for all classified advertisements is 6d. per word ; in bold print 9d. per word ; minimum order 6s. Box-number advertisements 1s. extra. Instructions, together with remittance, must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

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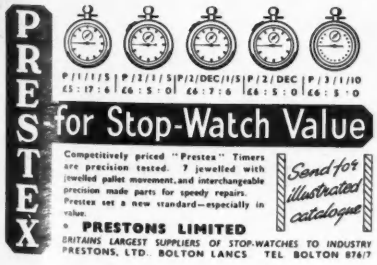
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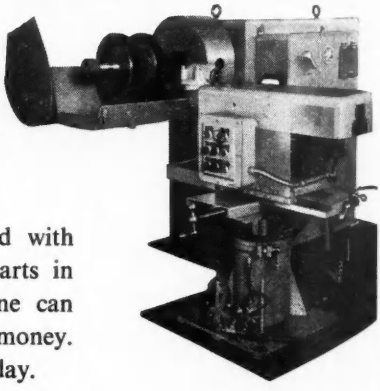

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BOOKS RECEIVED

Arcs in Inert Atmospheres and Vacuum. Edited by W. E. Kuhn. 196 pp., 113 illustrations. Publishers : John Wiley & Sons, Inc., N.Y., and Chapman & Hall Limited, 37 Essex Street, London, W.C.2. Price : 60/–.

This volume contains fourteen papers presented at a symposium on "The Electric Arc in Inert Atmospheres and Vacuum", which was held at the Spring Meeting of the Electrochemical Society Inc., U.S.A., in San Francisco in 1956. This collection of papers therefore makes the information released at the meeting available on a much wider basis to those working in the field of electric-arc technology.

The contents are divided into four sections, i.e., The Past and Present Status of High-Current Arc Technology ; Arc-Melting Fundamentals ; Design and Operation of Arc-Melting Furnaces ; and Chemical Applications of Arcs.

British Diesel Engine Catalogue. Fourth Edition. Edited by D. S. D. Williams, A.M.I.Mech.E. 365 pp., 800 illustrations. Publishers : Temple Press Limited, Bowling Green Lane, London, E.C.1. Price : 52/6.

Produced for the British Internal Combustion Engine Manufacturers' Association, this fourth edition of the British Diesel Engine Catalogue covers descriptions and tabulated information of nearly 2900 engines of 43 different makes, the total of engines mentioned being about 27% higher than that in the third edition. In this connection, several prominent engine manufacturers appear for the first time and, with their inclusion, there can be no doubt that this volume is an almost complete reference work of the British diesel-engine industry, insofar as the makers of stationary, marine, and rail-traction units are concerned.

On the whole, this volume follows the general lines adopted in the preceding issues, retaining its large format (13½ × 10 in.). Approximately 65% of the work is illustrated in colour, as well as black. In addition, the introductory portion of the book contains a wealth of interesting pertinent information on the industry, including technical information for the use of buyers and users, and a series of indices, one of which is the exclusive "Lightning" index for the rapid location of any information required.

The Malta Directory & Trade Index, 1957. 418 pages. Published by Malta Publicity Services Limited, Valletta, Malta. Price : 25/6.

Authoritative and comprehensive, this well-produced volume is an indispensable handbook for all those who are interested in the trade of the Maltese islands. Fully indexed and classified, there is no doubt that this is a most useful reference work of the almost 3000 firms in Malta and of the wide variety of goods and services they supply, in addition to being a useful survey of up-to-date general and commercial information regarding Malta.

Fuel Saving Charts. By Walter Goldstern, F.Inst.F., A.M.I. Mech.E. 38 pp., 24 illustrations. Publishers : John D. Troup Limited, 90 High Holborn, London, W.C.1. Price : 10/–.

Basically comprising a series of 24 articles reprinted from *The Steam Engineer*, this work has now been revised and includes 24 charts which have been brought up to date, where necessary, in respect of fuel costs, boiler ratings, oil-firing, etc.

The charts are designed to enable engineers to supervise the correct and efficient operation of steam and boiler plant by carrying out the necessary calculations quickly and easily, without the need to refer to data and formulae which may not be readily available. As a result, they provide a useful means of ensuring efficient operation of such plant, with a consequent saving in fuel.

Solution of Problems in Strength of Materials. Second Edition, 1957. By S. A. Urry, B.Sc.(Eng.), A.F.R.Ae.S. 444 pp., 174 illustrations. Publishers : Sir Isaac Pitman & Sons, Ltd., Parker House, Kingsway, London, W.C.2. Price : 20/–.

Intended for those engineering students who prefer the study of specific problems in connection with the strength of materials to the more general approach of orthodox textbooks, this new and up-to-date second edition is in itself a practical textbook, each chapter of which comprises a number of fully worked-out problems, showing the derivation of essential formulae and their numerical applications. These are followed by appropriate exercises, with answers, to give students practice, while at the beginning of each chapter a short summary is given of essential definitions and formulae.

In addition, a useful appendix is included, covering the proper analysis of laboratory test results. In this edition, the author has added several problems and test papers, and a new chapter on "Mechanical Properties and Theories of Failure".

Symposium on Vacuum Technology. Edited by Edmond S. Perry and John H. Durant. 242 pp., 377 illustrations. Publishers : Pergamon Press, 4 & 5 Fitzroy Square, London, W.1. Price : 90/–.

Containing the complete proceedings of the Symposium on Vacuum Technology, sponsored by the Committee on Vacuum Techniques, of Boston, Massachusetts, and held in Chicago in October 1956, this well-produced volume comprises the forty papers presented and, for convenience, has been divided into a number of classifications. Thus, several papers are devoted to fundamental developments in vacuum technology, and a number to methods and techniques for obtaining high vacuum. Other papers cover instrumentation, controls, and other vacuum devices ; vacuum distillation ; metallurgical and chemical applications ; and technical subjects of current interest. In addition, a useful glossary of terms used in vacuum technology is included.

Undoubtedly, this handy and authoritative collection of papers provides an up-to-date source of information to all those concerned with high-vacuum work.

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2. Snap-Action Micro-Switches. In an excellently produced and illustrated 50-page catalogue, bound in a loose-leaf folder, full details are given of a comprehensive range of snap-action micro-switches, housed in precision-moulded bakelite cases.

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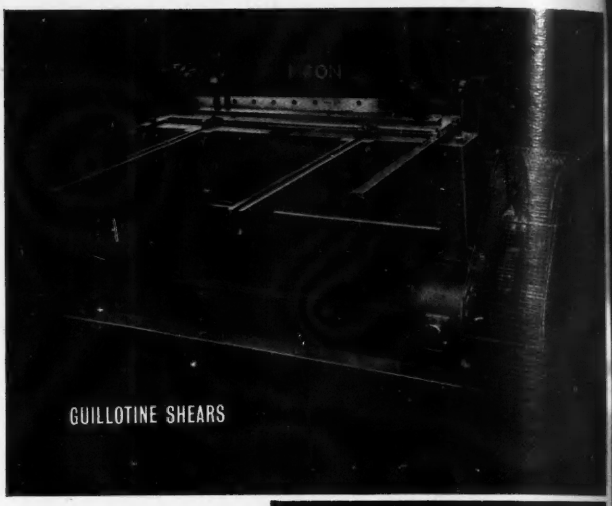

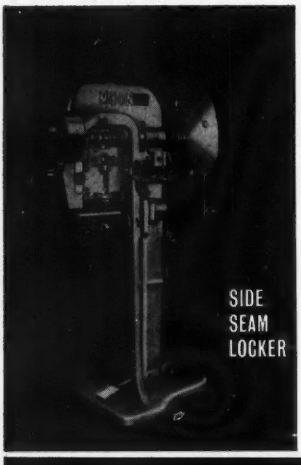

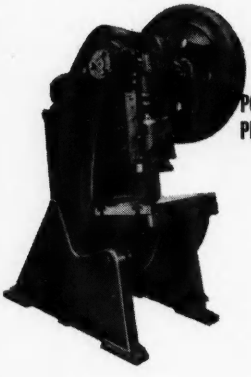

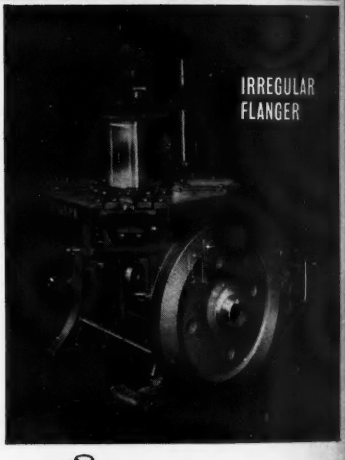

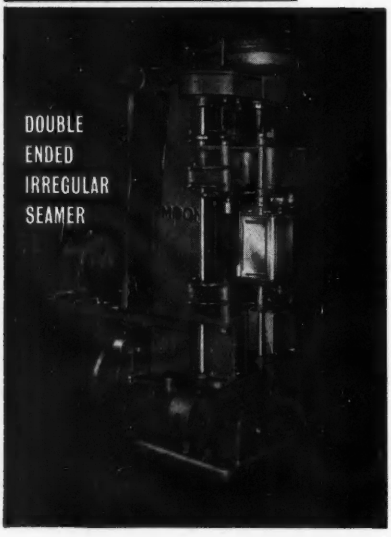

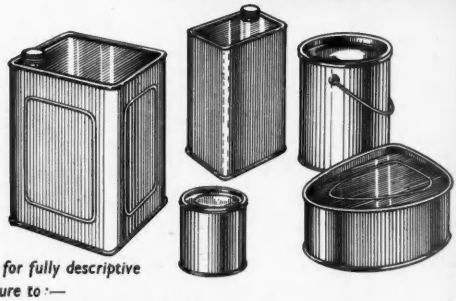

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